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A Case Study on Safe Blast Design with Vibration Analysis

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ABSTRACT

Safe delicacy blasting is necessarily to decrease safe problems resulting from blasting, but if designs to consider only safety, it is a problem not to ensure economical gains because the effect of blasting is decreased. Therefore, blasting vibration must be predicted to consider given circumstances and ground conditions before blasting work, and then a design based on predicted result must be done.

In this study, the testing blasting was carried out in two fields within a country, and then measured data for testing blasting were collected. The effect for blasting vibration was analyzed as the property of distance, charging gunpowder capacity, surrounding conditions, and measured points. The test results were performed by back-analysis, and compared with previous research results. Therefore, it will be proposed an effective prediction and design.

1. NTRODUCTION

Recently, it is a fact that construction projects for facility expansion of social overhead capital are brisk, and increasing in the downtown area as well as a mountainous area. Blasting works cause problems of ground vibration, blasting noise, particulate and so on. Especially, dense buildings can cause a civil petition discontent that give inconvenience to local residents, and careful attention is requested because sensitive machinery to vibration can give fatal damage.

The direct causes of damage by blasting are stress wave of the part close to explosion radius, and the outbreak of crack by propagation wave. The damage by ground vibration also can occur in some distance from explosion radius. Therefore, It must be reviewed the effect of contiguous structure that is predicted by ground vibration before blasting work.

Safety accuracy blasting is necessary to reduce safety problem by blasting, but it has problems that the efficiency of blasting diminish, and the economical efficiency is not secure. Hence, the blasting vibration must be predicted to consider about the surrounding situations and ground conditions, and the design must be based on it.

Until now, the blasting works has been performed due to experience because the study of this case is not much. The research about blasting vibration for reasonable design is insufficient.

So, in this research, the predictable data was collected about blasting vibration after executing a testing blast in two domestic fields, and then the effect for it was analyzed due to the characteristics of distance, a charge of gunpowder, surrounding conditions, and measurement point. I want to suggest an effective prediction design as comparing with existing theory.

2. PREVIOUS RESEARCH

The prediction of blasting vibration has been carried out in plan stage of ground excavation. Therefore, the design parameters related to surrounding circumstance must be appropriately controlled for safety blasting design. The control of design parameters is possible under analyzing the characteristics of the collapse mechanism of rock, blasting vibration, blasting wind, and flying rock, and under sufficiently grasping the effect of several design parameters.

The blasting causes the vibration on the ground as the part of explosion energy is waved in the rock, and it is affected by several causes. The factors related with blasting causes are the kind of used gunpowder, a charge of gunpowder, the specific gravity and intensity of gunpowder, and the velocity of blasting. The factors related with the rock are the density, intensity, and elastic modulus of the rock, the joint surface, and the distribution of a surface of discontinuity in the rock, and so on.

The factors related with blasting pattern are hole diameter, hole space, minimum resistance line, tamping, the setting method of gunpowder, parallax, the distance between explosion radius and measurement point, and so on.

The vibration velocity of many factors is in proportion to a charge of gunpowder per hang fire, and in inverse proportion to the distance. The attenuation characteristics of the ground have different important characteristics due to geology conditions and the applied rock conditions. Various formulas to predict vibration velocity has been suggested on the basis of research result (Table 1).

A square and cubic root scaling

$$V = K_s\left(\frac{D}{\sqrt{W}}\right)^{-ns} \quad (1)$$

$$V = K_c\left(\frac{D}{\sqrt[3]{W}}\right)^{-nc} \quad (2)$$

Here, V: the velocity of a particle (cm/sec)

D: the distance with blasting radius (m)

W: a charge of gunpowder per hang fires (kg)

Ks: blasting vibration constant of square root scaling

ns: attenuation index of square root scaling

Kc: blasting vibration constant of cubic root scaling

nc: attenuation index of cubic root scaling

Site specific scaling

$$V = KD^{-n}W^{b} \quad (3)$$

Here, K: blasting vibration constant

n: attenuation index

b: gunpowder index

The gunpowder index is suggested experimentally in case of the Bureau of Mining of the U.S., and it is a conversion formula of a square root. It is on the basis of dimension analysis theory that a conversion formula of a cubic root is applied to suggest gunpowder index, 1/3.

With a conversion formula due to location characteristics, it can be determined gunpowder index from that the vibration level to a charge of gunpowder can be evaluated as fix the distance, and vary a charge of gunpowder, and from that vibration level to the distance is compounded as fix a charge of gunpowder, and vary the distance.

In an estimated formula of blasting vibration velocity, the characteristics of attenuation about geotechnical properties and blasting conditions, is influenced by the blasting vibration constant and attenuation index. Therefore, it is very important to determine these constants in case of blasting design.

Table 1. The estimated formula proposed to blast vibration.

Researcher	The estimated formula	Blasting vibration constant
U.S.B.M	$V = K\left(\frac{D}{W^m}\right)^n$	m : Index due to a charge of gunpowder n : Attenuation index due to distance K :Blasting vibration constant
Lee Dung	$V = KW^{2/3}D^{-2}$	K : 250-100 a colloid dynamite K : 15-21
Langefors	$V = KW^{0.5}D^{-0.75}$	K : 300-700
Gil Cheon	$V = KW^{2/3}D^{-2}$	K : 100-700 (Tunnel K =150-650)

Kim in Korea suggested the result of back analysis by square and cubic root scaling to be able to apply to predict blasting vibration velocity in granite, gneiss, and lime.

Lim presented that the result of analysis for frequency characteristics due to rock blasting was in the range of blasting vibration frequency, 10-90Hz, and compared with the influence of earthquake frequency.

Also, he presented allowable standard of blasting vibration size that allowable vibration value must be applied to 1-2cm/sec in vibration frequency 10-35Hz, and below 5cm/sec over 35Hz.

Table 2. The estimated formula of vibration velocity proposed in Korea

Researcher	Bedrock condition	Conversion distance	Blasting vibration formula
Kim et al. (1994)	Granite Gneiss Lime	A cubic root	K=135.6, n=-1.80 K=114.0, n=-1.70 K=273.8, n=-1.60
Lee et al. (1991)	Granite Gneiss	A cubic root	K=128.0, n=-1.754
Lim et al. (1992)	Gneiss Sandstone Granite	A cubic root	K=36, n=-1.337 K=14, n=-1.014

3. BLAST CONDITION IN FIELD

3.1 Site A

This field is one of construction areas of an expressway that has many hilly districts and many rock cuttings to work, and that need to blast in detail because it is surround with a filtration plant, school, a densely populated district at surrounding.

The geologic of this site based on the gneiss belongs to Pre-Cambrian period on geological history. The rock-forming minerals are intersected by quartz, plagioclase, and biotite or remained in a figure. The gneiss, bedrock, had weathered. It has the characteristics of extreme stratification, joint and irregular at a direction, which is a level of hard or normal rock for R.Q.D. 83.3%, the unconfined compression strength 512~658 kg/cm^2. Gelatin dynamite 50m/m is used as gunpowder, and blast pattern of exploder (ED, MSD) is bench cut.

3.2 Site B

The rock-blast zone was happened during estate development work for housing construction, and it had a sensitive fabric to vibration and a densely populated district in the surrounding. Especially, it needs a precise blasting work because vibration influences on main measuring equipment and much computer system.

In this zone, geology composed of bedrock composed of granite of the Mesozoic Jurassic in penetration for the gneiss of pre-Cambrian period, is a solidity rock with granular quartz and orthoclase and a small biotite. The weathering degree of bedrock is the development for weathering to deep layer. The composition strength is widely distributed to 250 ~ 1200 kg/cm^2 , and it is estimated for hard rock or extremely hard rock. The gunpowder used on a test blast was water-gel explosive and enforced moment blast and delaying blast side by side.

4. BLAST DESIGN WITH VIBRATION ANALYSIS

4.1 Measuring value of vibration velocity due to a conversion distance

Changing into the location and a charge of gunpowder, the measurement was enforced to forecast vibration velocity due to a conversion distance. It is variously distributed the physical properties of rock of located area.

It is changed blasting point as guidance for relative formula to spread characteristics of vibration of ground. Also, it is enough reflected change of blasting point, charge weight, measuring point with controlling of the charge of gunpowder weight and distance from explosion radius. The Fig. 1 is vibration velocity of area A due to a conversion distance. The more get away the distance from explosion radius, the more reduce degree of vibration. A part of area could be seen an increase phenomenon of another vibration as direction of development of bedrock. Therefore, it was discovered that the basis of distance is not always proportional to blast vibration.

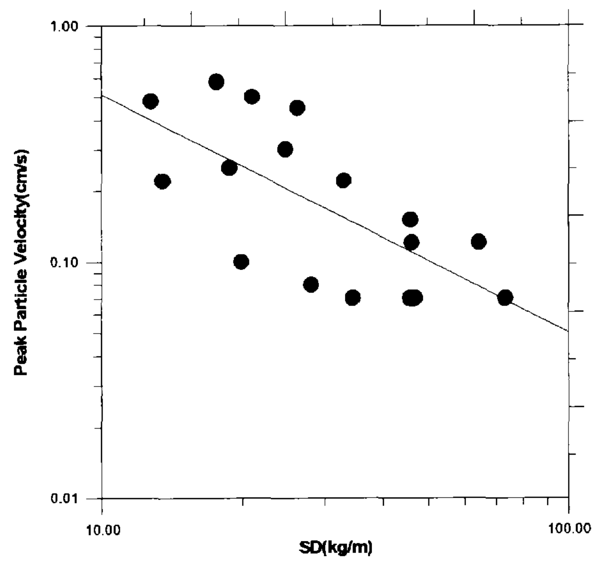

Fig. 1. Vibration velocity due to conversion distance (Area A)

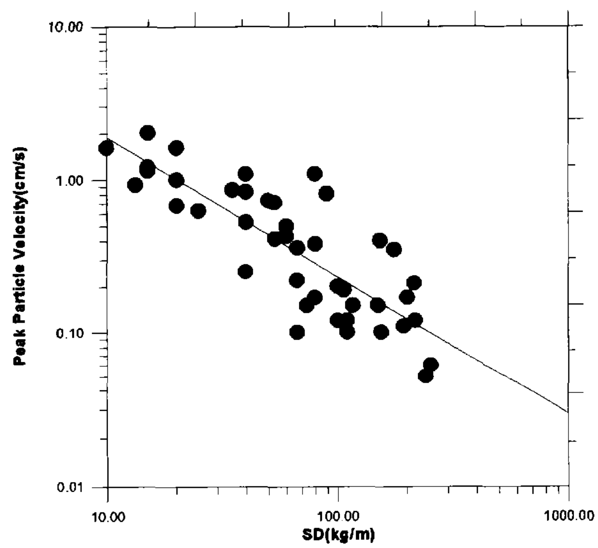

Fig. 2. Vibration velocity due to conversion distance (Area B)

In some cases, blast vibration was discovered beyond so that the joint of bedrock affects blast velocity. Fig. 2 shows vibration velocity due to the conversion distance, and it was by ground vibration rather than blasting pressure to avoid triggering by surrounding noise. The level of trigger had 0.06 cm/sec on minimum value of measuring equipment. In this investigation result, the vibration velocity reduced to the increase of the conversion distance and it showed result with comparative confidence.

4.2 The comparison of previous study result with measuring value in Korea

The blasting vibration method proposed for considering to a given condition of domestic is different kinds. In this study, a representative three ways of them was applied on data analysis, and the result was illustrated on Figs. 3 and 4.

The area A with the applied result was discovered to coincide better with this in-site as the coefficient of crystallization 0.828 by method of Kim's proposed the blasting vibration method due to kinds of rock.

It was 0.82 by Lim's formula and 0.811 by Lee's formula. Theses three coefficients over 0.7 was estimated confidence comparatively.

The area B is discovered to coincide better with this in-site as the coefficient of crystallization 0.70 from Kim's formula. It was 0.694 by Lim's formula and 0.687 by Lee's formula. All the three formula were absolutely evaluated with formula proposed in domestic.

4.3 Decision of a vibration constant and a decrement index for back analysis

As using measured data, square and cubic root scaling were recurred for analysis and the result is shown in Figs. 5 ~ Fig. 8.

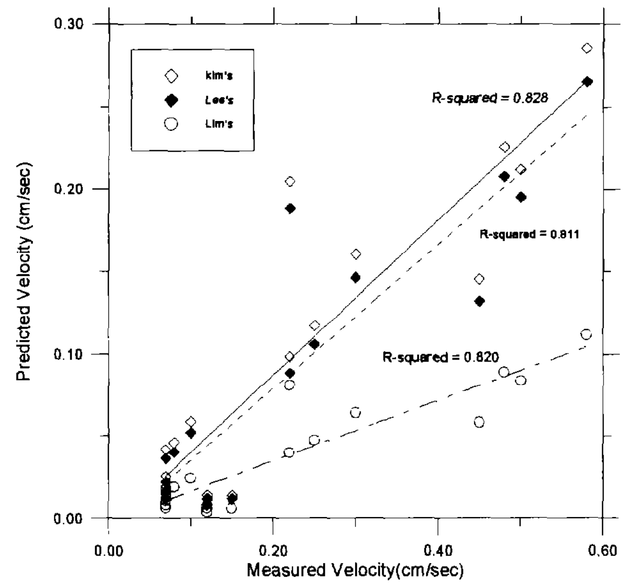

Fig. 3. Comparison of the correlation coefficient with proposed blast vibration equations (Area A)

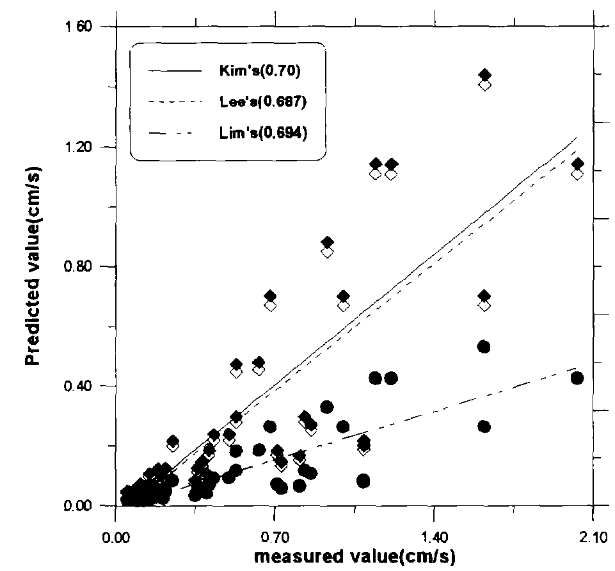

Fig. 4. Comparison of the correlation coefficient with proposed blast vibration equations (Area B)

A deduction formula of blasting vibration of area A was shown as following.

$$V = 9.799(D/W^{1/2})^{-0.96491} \quad (4)$$

$$V = 10.37(D/W^{1/3})^{-0.9228} \quad (5)$$

The result was discovered that it was larger than the reduction index of vibration of the granite gneiss proposed by domestic researchers. It is estimated that this cause by existing joint in bedrock, and being large altitude gap between initiation point and measurement point. Although the strength of faultless bedrock is generally big in the area has much joint, coefficient of vibration changes a little because of big joint gap. Area B is discovered as following, and the correlation coefficient shows over 0.8.

$$V = 50.67(D/W^{1/2})^{-1.272} \tag{6}$$

$$V = 69.19(D/W^{1/3})^{-1.38} \tag{7}$$

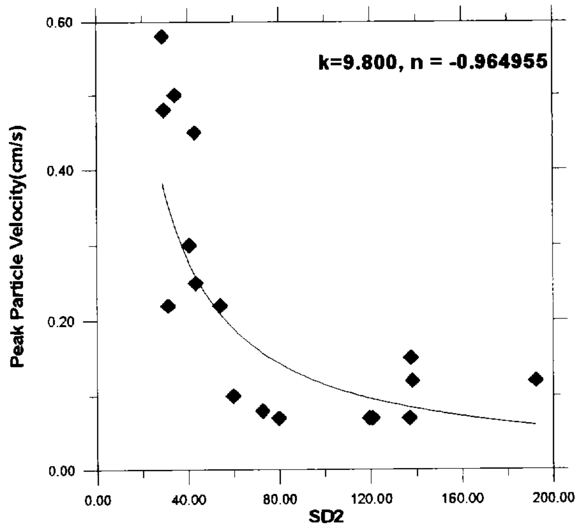

Fig. 5. Decision of a vibration constant and a decrement index for back analysis by conversion root of square root (Area A)

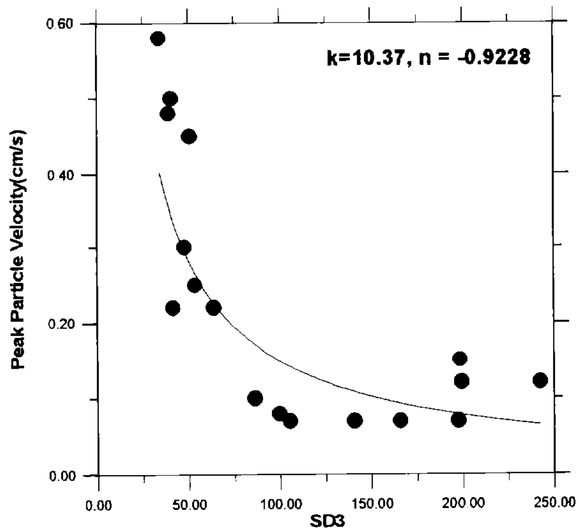

Fig. 6. Decision of a vibration constant and a decrement index for back analysis by conversion root of cubic root (Area A)

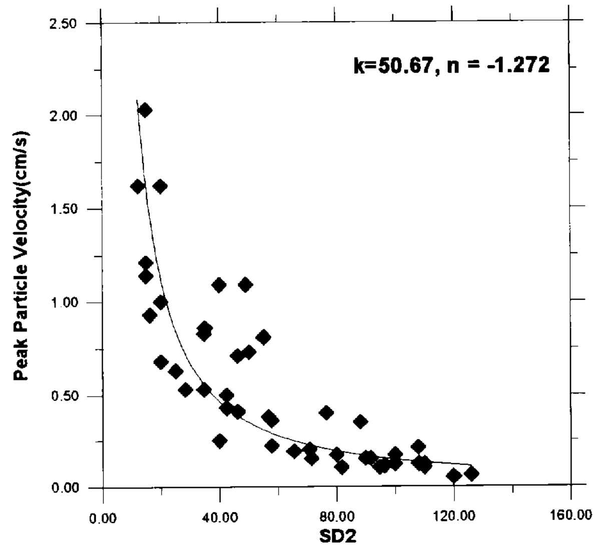

Fig. 7. Decision of a vibration constant and a decrement index for back analysis by conversion root of square root (Area B)

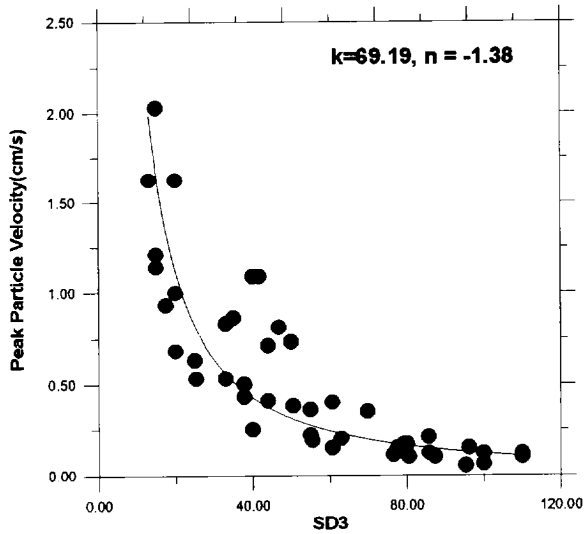

Fig. 8. Decision of a vibration constant and a decrement index for back analysis by conversion root of cubic root (Area B)

The calculated reduction index is discovered less than proposed values in domestic. The larger is the value as the vibration constant of blasting equals to a proportion constant, the larger is the particle velocity. The damage from blasting of this area estimated relatively little.

Also, it is no large difference an occasion of square and cubic root scaling in measuring data, but square root scaling at area A measured at area far away distant from explosion radius has confidence, and cubic root scaling at area B to small distant is discovered as high.

4.4 Comparison calculated with measured velocity

The calculated reduction index is discovered less than proposed values in domestic. The larger is the value as the vibration constant of blasting equals to a proportion constant, the larger is the particle velocity. The damage from blasting of this area estimated relatively little.

Also, it is no large difference an occasion of square and cubic root scaling in measuring data, but square root scaling

For estimating application of proposed vibration formula of blasting, the velocity was obtained by substituting the conversion distance for each formula to be back analysis and the result was compared with surveyed data. The formula included square and cubic root scaling, and conversion formula of location characteristics.

From analyzed result, it was 0.795, 0.771 in case of square and cubic root scaling and 0.828, 0.812 in case of conversion formula of location characteristics in area A. Also, in case of area B, it was 0.708, 0.710 in case of square and cubic root scaling and 0.669, 0.664 in case of conversion formula of location characteristics.

The correlativity of blasting vibrating velocity counted back and measured shows correctness of a back analysis result. As shown Fig. 9, conversion formula of location characteristic is shown higher coefficient of correlation in Area A and the result of back analysis with square root or cubic root is indicated higher correlative degree in Area B. And also the result of vibration velocity with square or cubic root through back analysis result was large in area A and was estimated small in area B.

Therefore, square and cubic root scaling formula is evaluated to approach in fresh Area B more then Area A developed large joint.

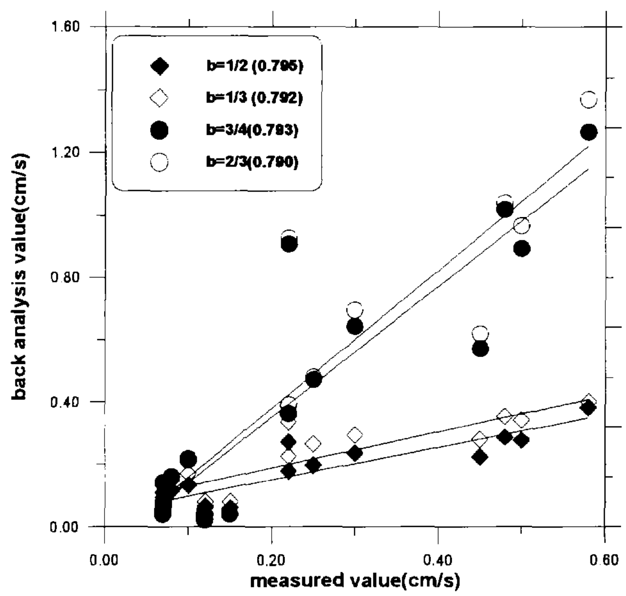

Fig. 9. Comparison calculated with measured velocity (Area A)

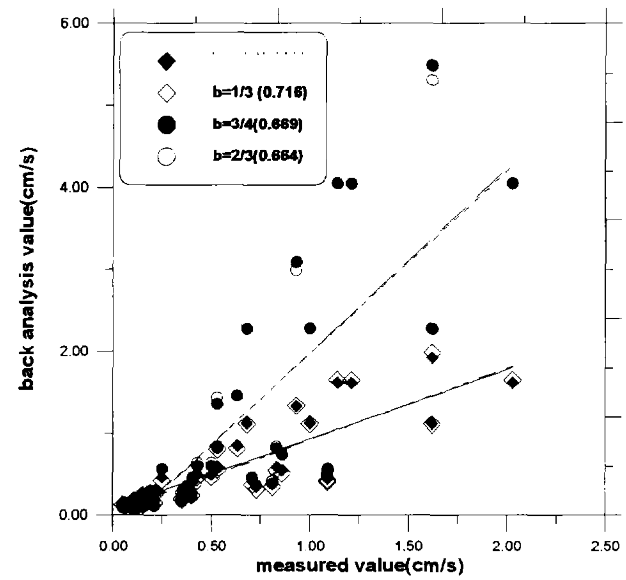

Fig. 10. Comparison calculated with measured velocity (Area B)

4.5. Examination of effects with blasting parallax

Blasting work for bedrock excavation of investigation zone is subjected to restriction on charge weight used from surrounding condition so that it is necessary to apply to delay blasting with parallax using delay detonator so as to get an effect of blasting more smoothly than limited powder weight.

So, to examine difference between instant and delay blasting was implemented, which had a detonator with 25ms and 250ms terms of delay. An oscillatory wave type was measured by using vibrating accelerator at a site 95m far from road width as a test blasting. It indicates that an oscillatory wave type and from 250ms parallax being free from intervention, each other shows independent wave type but from 25ms parallax, it forms one wave overlapping each other and also vibration level was shown larger than 250ms.

4.6 Reduced distance characteristic of blast pressure

The result expressed blast pressure level with dB for cubic root scaling is shown in following Fig. The result of back analysis of blast pressure indicated 0.5 in case of area A, 0.6 in case of Area B, so that it was of inferior reliance to vibrating velocity.

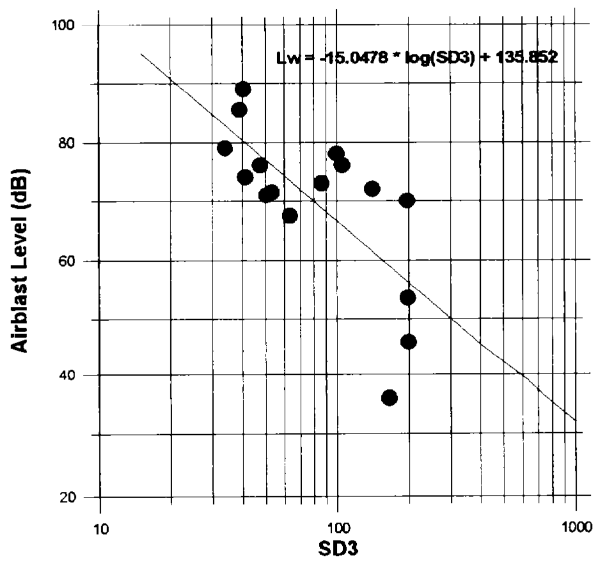

Fig. 11.Blast pressure level for cubic root scaling (Area A)

In accordance with weather and topographical condition, the propagation of blast pressure by blasting shows much difference, so that coefficient of determination in propagation equation is of inferior in competition with propagation of ground vibration.

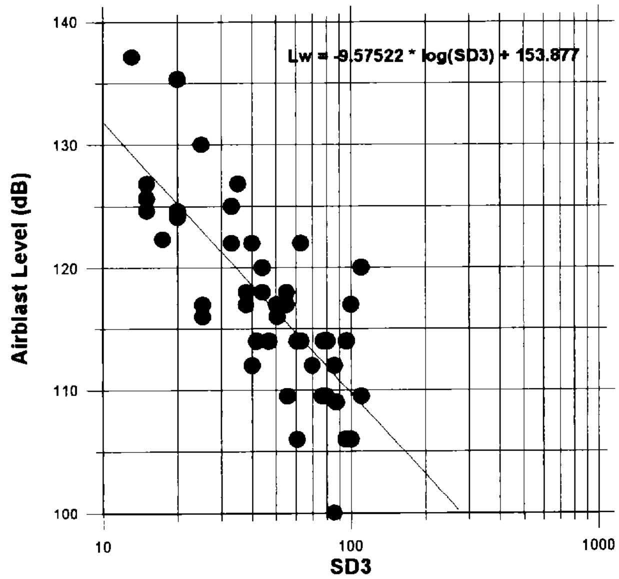

Fig. 12.Blast pressure level for cubic root scaling (Area B)

The representative equation from treating data is finding as following.

$$L_w = 135.852 + \log_{10}(\frac{D}{W_{1/3}})^{-15.0478} \quad (8)$$

$$L_w = 153.877 + \log_{10}(\frac{D}{W_{1/3}})^{-9.57522} \quad (9)$$

5. SAFETY BLASTING DESIGN

The vibration level related to using charge of gunpowder and distance is shown in following equation (10), (11), but considering about safety, expected equation to use design in investigation zone predicted upper limit values of vibrating and the level didn't exceed a tolerance limit as using an equation including all measuring data.

$$V = 15.872(D/W^{1/2})^{-0.965} \quad (10)$$

$$V = 220.3(D/W^{1/3})^{-1.424} \quad (11)$$

Allowable vibration level of blasting is various, not to be regular due to selected structure and many researchers in the world were applying to different allowable standard respectively. In this study, allowable standard value is determined 0.1 ~ 0.5 cm/sec every position with reference to allowable standard of blasting in Ministry of Construction and Transportation in Korea.

Table 3. Allowable standard of blasting in Ministry of Construction and Transportation in Korea

Building	Allowable value (cm/sec)
Sensitive building With cultural assets	0.2
House and apartment	0.5
Commercial quarter	1.0
Build and factory made with reinforced concrete	1.0 - 4.0

In blasting working, distance is the shortest distance from explosion radius to measuring site or body and structure of security, and in case of working place of blasting to use same charge weight. It is the more approach from explosion radius, ground vibration is the bigger geometrically.

Therefore, doing blasting working for cutting rock, we have to determine charge weight to consider about rationality and efficiency of work in road construction site.

As blasting with 10kg charge a blasting in area, the volume of cutting is about 600m. So after checking blasting distance, it is shown that slight shock blasting is had to perform below 190m and 95m in case of considering about security of important facilities. The charge of gunpowder and the distance due to allowable vibration velocity were plotted in Fig. 13 and Fig. 14. After using analysis result until now we have carried out safety blasting design as following Table 4.

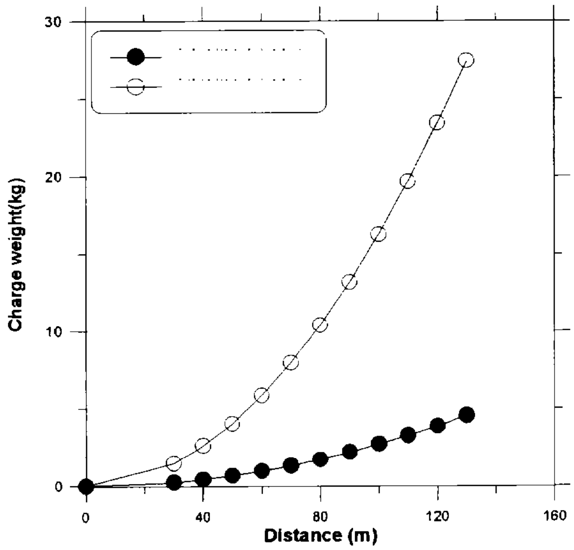

Fig. 13. The charge of gunpowder and the distance due to allowable vibration velocity

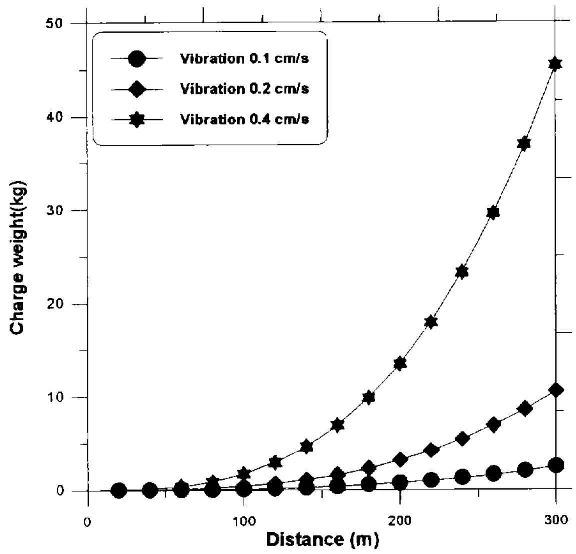

Fig. 14. The charge of gunpowder and the distance due to allowable vibration velocity

Table 4. Summary of safety blasting design

	Area A	Area B
Blasting method	Bench cut	Bench cut
Bench height (mm)	1800	1600 ~ 2000
Using explosives	Dynamite	Water-gel explosives
Blasting agents	ED, MSD	ED, MSD

Cartridge diameter (mm)	28	28
Cartridge length (mm)	271	390
Weight of unit (g/unit)	200	250

6. CONCLUSION

(1) It shows a general tendency that the intensity of vibration due to conversion distance reduces as it is far from explosion radius. It shows that another increment phenomenon of vibration indicates due to joint direction of bedrock in a part. Therefore, it shows that the origin of distance is not always in proportion to blasting vibration

(2) It indicates that blasting vibration formula suggested as consider a given condition of the domestic exceed correlation coefficient 0.7, and it is estimated that reliable prediction is possible.

(3) It indicates that attenuation index and blasting vibration constant distributes variously due to blasting, geology, and location condition. It shows that the prediction by testing blast is appropriate.

(4) It was proved that Hang fire blasting applied to get available blasting effect is useful. The detail measurement is needed because a decision coefficient reduces in case of wave of explosion pressure due to conversion distance than wave of ground vibration.

(5) It is judged that it can be induced a valid prediction formula when this case study must be carried out in similar condition because this research is the result for surrounding circumstance of limited local.

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