Careful Blasting to Reduce the Level of Ground Vibration in Open Excavation

노천 굴착에서 발파 진동의 크기를 감소시키기 위한 정밀발파

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Abstract

In this paper, ground vibration and other properties measurements were conducted to determine empirical equation based on careful test blasting with crawler drill(diameter 70−75mm).

The empirical euqations for ground vibration are obtained as follows

$V=41(D/\sqrt[3]{W})^{-1.41}$ $30m \leqq D \leqq 100m$

$V=124(D/\sqrt[3]{W})^{-1.66}$ $100m \leqq D \leqq 285m$

where V is peak particle velocity in cm / sec,

D is distance in m and

W is maximum charge weight per delay in kg

1. Introduction

Explosives are widely used to break rock in mining, quarrying and civil engineering. These blastings have recently increased complaints due to ground vibrations, fly rock, and air blast.

In order to excavate effectively some foundation site within allowable vibration level, careful blasting was used in the Samcheonpo area.

For several years some studies[1, 2, 3, 7] have paid special attention to the examination and minimizing of unwanted structural damage due to blasting. The level and characteristics of the empirical equations depend on many factors and blasting patterns etc. Variation in these factors produce different results and they must be taken into account to make the best empirical equations.

The objectives of this paper are ; (1) to determine the empirical vibration equation, (2) to evaluate the effect of milli−second deck firing.

2. Mesurement of Ground Vibrations

2.1 Instrumentation

A Instantal model DS 477 blastmate vibra-

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tion moniton with triaxial velocity transducer was used to record and measure the particle velocity. The natural frequency of vibration monitor is 5 to 200Hz within the range of the biasting frequency.[6]

The partiole velocity was calculated as the vector sum of three traces on the chart paper corresponding to longitudinal, vertical and transverse components of the ground motions at any given time. The maxlmum value of this vector sum taken as the peak particle velocity (P.P.V). The P.P.V was therefore greater than or equal to any of the peak component velo-clties.

2.2 Site conditions and Experimental Proc-edures

The blasting have been done with explosive (Kovex), electric milli-second delay caps, The hole with 75mm diameter, from 3 to 6m depth, was drilled with crawler drill and the bench cut was adopted. The rocks ared calcarious

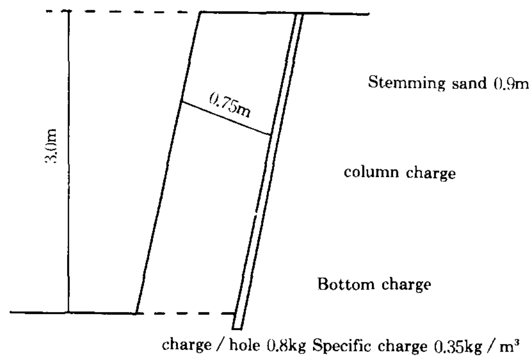


Fig. 1. Drilling pattern

sandstone(moderate-semi hard rock).

From 84 blasts, 55 blasts were monitored at distance of 30−98m(A zone), the other 29 blasts were also nomitored at distance of 100−286m(B zone) respectively. All monitoring was done on the same rock and aligned in a direction perpendicular to the row of shotholes, The results of measured ground vibration and scale distance for blasting vibration are given in Table 1.

Table 1. Results of measuring blast-induced ground vibration

Test	No of Holes	Drilled depth (m)	Distance (D) (m)	Charge(kg) Per hole	Charge(kg) Total	Charge(kg) Max delay	No of M / S caps(pcs) Per hole	No of M / S caps(pcs) Total	Scaled Distance b=1/2	Scaled Distance b=1/3	Remarks
1	84	3.75	80	3.455	290.22	22.5	3.5	294	16.87	28.33	A zone
2	88	3.69	80	3.606	317.25	23.625	3.46	304	16.46	27.82	
3	70	3.43	81	3.0445	213.115	12.9375	3.29	230	22.52	34.45	
4	45	3.67	72.5	3.5	157.5	10.125	3.45	155	22.78	33.46	
5	35	3.48	64	3.134	109.6875	6.75	3.32	116	24.63	33.82	
6	41	6.0	89.5	5.625	230.625	16.875	4	164	21.78	34.83	
7	32	6.0	81	5.625	180	9	4	128	27.0	38.88	
8	32	6.0	81	5.625	180	9	4	128	27.0	38.88	
9	32	6.0	81	5.625	180	9	4	128	27.0	38.88	
10	26	3.12	64	2.467	64.125	4.5	2.16	56	27.0	38.73	
11	14	4.5	55.5	5.0625	70.875	5.0625	4	56	24.67	32.29	
12	14	4.5	55.5	5.0625	70.875	5.0625	4	56	24.67	32.29	
13	27	6.0	40	5.625	151.875	11.25	4	108	11.93	17.82	
14	52	3.0	98	2.25	117	6.75	2	104	37.72	51.79	
15	43	3.0	72.5	1.125	48.375	3.75	2	86	37.44	46.62	
16	16	4.5	64	2.25	36	2.25	4	64	42.67	48.81	
17	16	4.5	64	2.25	36	2.25	4	64	42.67	48.81	

Test	No of Holes	Drilled depth (m)	Distance (D) (m)	Charge(kg)			No of M/S caps(pcs)		Scaled Distance		Remarks
				Per hole	Total	Max delay	Per hole	Total	b=1/2	b=1/3	
18	30	3.0	64	1.125	33.7	3.375	2	60	18.96	42.63	
19	54	2.01	89.5	3.459	186.75	13.5	3.08	166	24.36	37.52	
20	40	3.0	81	2.25	90	6.75	2	80	31.18	42.81	
21	70	3.45	89.5	2.925	204.75	13.5	2.6	182	24.36	38.63	
22	40	3.75	81.5	3.375	135	12.375	3	120	23.17	35.18	
23	50	3.0	81.5	2.25	112.5	9	2	100	27.17	39.12	
24	42	3.0	81	2.25	94.5	6.75	2	84	31.18	42.81	
25	18	6.0	81	5.625	101.25	7.875	4	72	28.86	40.66	
26	36	4.5	81	4.5	162.0	12.9375	4	144	22.52	34.45	
27	32	4.5	89	4.5	144.0	9.0	4	128	29.67	42.72	
28	32	4.5	81	4.5	144.0	9.0	4	128	27.0	38.88	
29	30	4.5	81	4.5	135.0	9.0	4	120	27.0	38.88	
30	49	3.0	81	1.6875	82.6875	5.0625	2	98	36.0	47.12	
31	39	4.5	89.5	4.5	175.5	13.5	4	156	15.11	37.52	
32	16	4.5	55.5	4.5	72.0	4.5	4	64	26.16	33.58	
33	16	4.5	55.5	4.5	72.0	4.5	4	64	26.16	33.58	
34	16	4.5	55.5	4.5	72.0	4.5	4	64	26.16	33.58	
35	16	4.5	55.5	4.5	72.0	4.5	4	64	26.16	33.58	
36	36	3.0	55.5	1.6875	60.75	3.375	2	72	30.21	36.97	
37	60	6.0	98	5.625	337.5	22.5	4	240	20.66	34.64	
38	24	3.0	55.5	1.6875	40.5	3.375	2	48	30.21	36.97	
39	20	3.0	55.5	1.6875	33.75	3.375	2	40	30.21	36.97	
40	24	3.0	55.5	1.6875	40.5	3.375	2	48	30.21	36.97	
41	20	3.0	55.5	1.6875	33.75	3.375	2	40	30.21	36.97	
42	20	3.0	55.5	1.6875	33.75	3.375	2	40	30.21	36.97	
43	30	4.5	81	4.5	135.0	9.0	4	120	27.0	38.89	
44	30	4.5	81	4.5	135.0	9.0	4	120	27.0	38.89	
45	16	6.0	55.5	5.0625	81.0	5.0625	4	64	24.67	32.29	
46	20	3.0	64	1.6875	33.75	3.375	2	40	34.84	42.63	
47	20	3.0	64	1.6875	33.75	3.375	2	40	34.84	42.63	
48	16	6.0	55.5	5.0625	81.0	5.0625	4	64	24.67	32.29	
49	20	3.0	64	1.6875	33.75	3.375	2	40	34.84	42.63	
50	32	6.0	60	5.625	180	11.25	4	128	17.89	26.80	
51	29	3.0	65	1.6875	48.9375	3.375	2	58	35.38	43.35	
52	29	3.0	65	1.6875	48.9315	3.375	2	58	35.38	43.35	
53	16	4.5	65	4.5	72.0	4.5	4	64	30.64	39.39	
54	9	6.0	33	5.625	50.625	9.5625	4	36	10.67	15.52	
55	9	6.0	33	5.625	50.625	5.625	4	36	13.92	18.57	
56	69	4.13	102	4.378	302.0625	23.625	3.76	259	20.99	35.47	B zone
57	81	4.19	102	4.473	362.25	25.875	3.79	307	20.05	34.41	
58	77	4.5	150	5.0625	389.8125	25.3125	4	308	29.81	50.98	
59	59	4.5	150	4.834	285.1875	20.25	4	236	28.57	54.92	
60	112	3.53	100	3.617	405.0	27.5625	3.36	376	19.05	33.03	
61	110	3.55	100	3.631	399.375	24.1875	3.37	370	20.33	34.50	
62	65	4.5	109	5.0625	329.0625	20.8125	4	260	23.89	39.55	
63	65	4.5	105.5	5.0625	329.0625	20.8125	4	260	22.25	36.82	
64	69	4.07	177.5	4.248	293.0625	25.3125	3.42	236	35.28	60.32	
65	97	4.40	160.5	4.860	471.375	30.375	3.93	381	29.12	51.32	

Test	No of Holes	Drilled depth (m)	Distance (D) (m)	Charge(kg)			No of M/S caps(pcs)		Scaled Distance		Remarks
				Per hole	Total	Max delay	Per hole	Total	b=1/2	b=1/3	
66	63	6.67	143.5	6.215	391.5	33.75	4.29	270	24.70	44.30	
67	77	3.84	143.5	3.836	295.3125	25.3125	3.12	240	28.52	48.77	
68	61	9.0	160.9	7.875	480.375	32.0625	5	305	28.34	50.40	
69	52	9.0	169	7.875	409.5	31.5	5	260	30.11	53.39	
70	43	6.0	168.5	5.625	241.875	16.875	4	172	41.02	65.57	
71	47	4.5	168.5	5.0625	237.9375	15.1875	4	188	43.24	67.92	
72	27	6.0	118.5	5.625	151.875	11.25	4	108	35.33	52.80	
73	21	9.0	168.5	7.875	165.375	15.75	5	105	42.26	67.10	
74	21	9.0	168.5	7.875	165.375	15.75	5	105	42.26	67.10	
75	48	3.0	109	2.25	108	6.05	2	96	44.31	59.75	
76	60	3.0	118.5	1.125	67.5	4.5	2	120	55.86	71.70	
77	54	4.5	185.5	5.0625	273.375	20.25	4	216	41.22	67.92	
78	54	4.5	195.7	5.0625	273.375	20.25	4	216	43.49	71.65	
79	52	4.5	200.5	5.0625	263.25	20.25	4	208	44.56	73.41	
80	71	4.5	285.5	5.0625	359.4375	25.3125	4	284	56.75	97.03	
81	59	4.0	265.5	4.110	242.4375	19.6875	3.33	196	59.84	98.13	
82	64	4.5	126	4.5	288	18	4	256	29.70	47.99	
83	64	4.5	109	4.5	288	18.	4	256	25.69	41.51	
84	36	6.0	185.5	5.625	202.5	16.875	4	144	45.16	72.18	

INSTANTEL DS477 BLASTMATE
VIBRATION RECORD 1

SERIAL # 678 V 3.1
TRIGGERED tran. at 04 : 19 : 12
09 Jan. 1990

	TRAN	VETR	LONG
PPV	6.201	3.225	2.853mm / s
FREQ	>100	51	64hz
TIME	388	387	659ms
ACCEL	0.42	0.18	0.11g

PK DISF:

1/4 WAVE	0.019	0.011	0.009mm
TOTAL	0.075	0.080	0.062mm

INSTANTEL DS477 BLASTMATE
VIBRATION RECORD 2

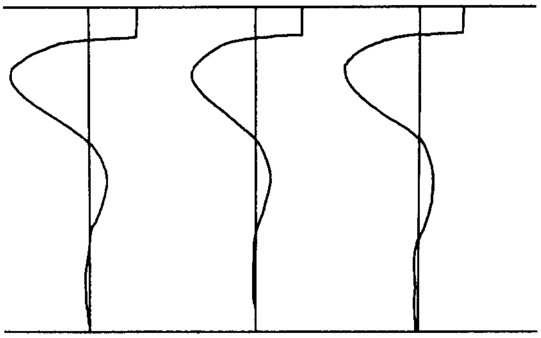
SERIAL # 678 V 3.1
TRIGGERED long. at 04 : 24 : 55
09 Jan. 1990

PPV	4.093	2.853	5.333mm
FREQ	73	51	37hz
TIME	224	71	796ms
ACCEL	0.23	0.18	0.27g

PK DISP:

1/4 WAVE	0.011	0.010	0.019mm
TOTAL	0.077	0.088	0.081mm

SENSORCHECK(tm) CALIBRATION



Calibrated 22 June 1988
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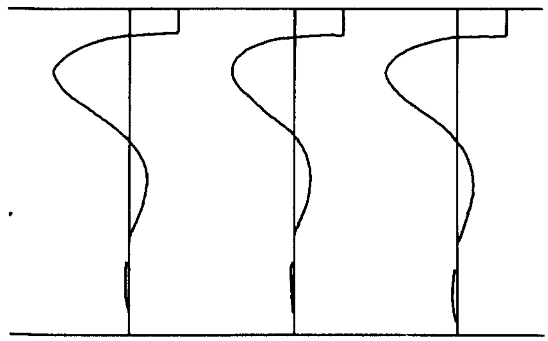

Calibrated 22 June 1988
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3. Results and Discussions

3.1 Empirical equation of measured vibration

The magnitude of the ground vibration and air blasts at any given position will vary according to the charge weight of explosives that is detonated and the distance from the blast.

In general, the propagation law has the following form;

$$V=K(D/W^{b})^{-n} \qquad (1)$$

where, V: peak particle belocity(P.P.V)

K: P.P.V intercept

D: distance from blast to measuring point

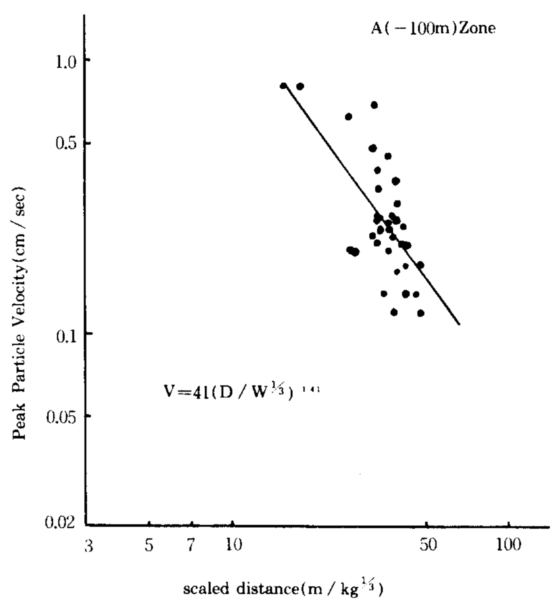
W: charge weight per delay

The attenuation exponent, n, was determined by the regresstion method and n are constants associated with a given site.

In an attempt to predict the ground vibration from blasting 85 vibration redordings were analyzed. Peak particle velocity was plotted directly aginst scaled distance and best fit was obtained by use of the least squares estimation of non-linear parameters.

Fig. 2 shows the scale distance for blasting vibrations. The typical vibration costants are estimated to be 41(A zone) to 121(B zone) for K and 1.41(A zone) to 1.66(B zone) for n.

It must be noted that since the geometry of the pits is complex in three dimensions, in this study only horizontal distances are taken into consideration and the conditions vary from blast to blast and site to site. Therefore considerable scatter in measurements is expected.



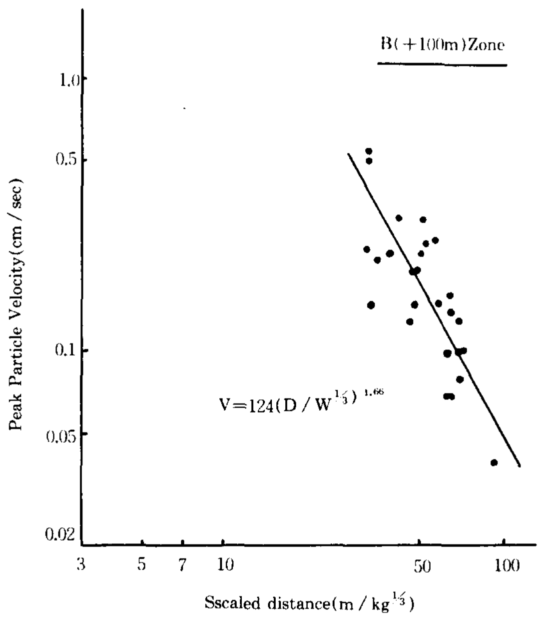


Fig. 2. Scaled distance vs peak particle velocity

3.2 Explosive type

Our previous studies(1, 4) have shown that ground vibrations can be reduced by the use of explosives that have low density and low velocity of detonation, such as Kovex, beacuse the detonation pressures and peak blasthole pressures are significantly lower than those of gelatine, ammonium dynamite and slurry explosive. In this experiment only Kovex was used. The charcateristlcs of some explosives which are produced in Korea are represented in Table 2.

Table 2. The characteristics of explosives

explosives / classification	Gelatine dynamite	Kovex explosives
Diameter(mm)	25	25
Length(mm)	182−186	206−280
Weight(gr)	112.5	150
N.G(%)	64−44	
Detornation velocity	5000−5500	3900

3.3 Deck charging of shothole

The magnitude of the ground and air vibrations at any location will be reduced if maximum charge per effective delay is reduced. This will be achieved by deck charging the shotholes and firing each deck on a seperate delay period(Fig.3).(5) Maximum five deck charging was adopted to reduce vibration in this test.

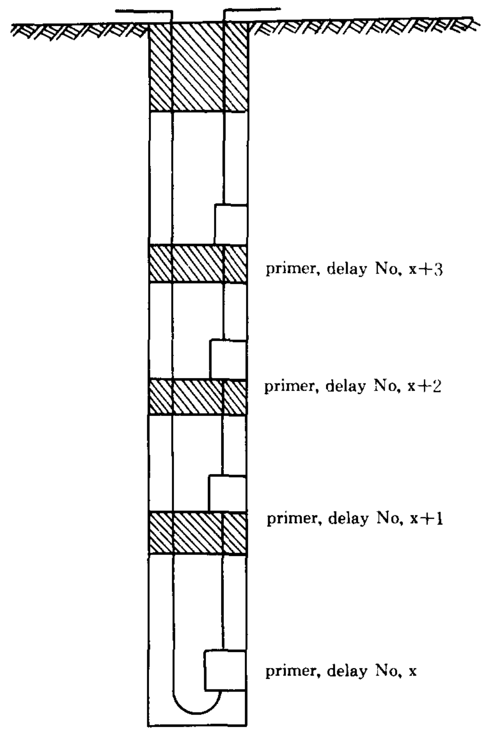


Fig. 3. Deck charging of shothole with initiatioin of each deck on seperate delay period.

3.4 Frequency of vibratioins

The principal frequency of a blast vibration can vary between 0.5 to 200Hz,(5, 6) but certain types of blasting tend to produce frequencies in a more limited range. The relatively large explosives produced by surface mining tend

Table 3. Comparison of some empirical equations in Korea

Site	Dongyang cement quarry(7)	Sang yong Donghae cement Quarry(3)	Seoul metrosubway corp(1)	S area project
Kind of rock	limestone	limestone	Granite & Gnis	calcarious sandstone
$Sc(kg/cm^2)$	820±150	400−1200	350−1450(granite) 850−1400(granite)	600−1100
P wave velocity (m / sec)	6000±500	3200−5400	−	−
explosive used	ANFO (primer: gelatine)	ANFO (primer: gelatine)	Gelatine, ammonium dynamite, slurry	Kovex
delay charge (kg)	50−472.5	723−5920	0.1125−7875	2.25−23.625(A aone) or 4.5−33.75(B zone)
distance (m)	95−679	331−2214	under 30	30−98(A zone) 100−289(B zone)
Constants			(granite)(gneiss)	(Azone) (Bzone)
K	45.24	513−648, 24−48	60−138, 48−107	41 124
n	1.80	1.88-1.64, 0.997-1.46	1.5-1.71, 1.57-1.78	1.41 1.66
b	1/2	1/3 1/2	1/3 1/3	1/3 1/3
Frequency		20−30Hz	about 100Hz	25−88Hz

to produce vibrations with lower principal frequencies than those of construction blasts. Construction blasts involve smaller explosions, but the typically small distance between a surface and a blast tend to produce the high frequencies.[6] Frequency range of blasting vibration must be considered to check the effect on damage.

Dominant frequences in this study are in the range of about 22−88Hz. Some previous studies[1, 3, 7] on frequency are represented in Table 3.

The shifting of dominant frequency down to lower levels at long distance is apparent as shown in Table 3.

4. Conclusion

A total of 84 blasts were monitored to determine vibration equation and maximum charge weight per delay within allowable vibration level.

The result can be summarized as follows:

(1) The emperical equations for the ground vibration are given as followings

$$V = 41(D/\sqrt[3]{W})^{-1.41}$$

(distance: 30−98m)

$$V = 121(D/\sqrt[3]{W})^{-1.66}$$

(disatnce: 100−286m)

(2) By an analysis of the measured data, cube root scaling might be more reasonable than square root scaling.

(3) The magnitude of ground vibrations can be reduced further, first, by using explosives that have low density and low velocity of detonation such as Kovex; second, by adopting three or four stage deck charging; third by using 9 milli−second−25milli−

seconds electric caps.

要　旨

露天掘鑿에서 發破振動의 크기를 減少시키기 위한 精密發破

本 硏究 에서는 '89年 12月 1日～190年 1月 9日 사이에 2 火力發電所 3, 4號機 基礎工事發破 作業에서 振動節減을 最少化하기 위하여 中型 crawler drill(bit經 ϕ70～75mm)에 의한 精密發破作業; 使用爆藥은 Kovex, 點火는 M / S 雷管 그리고 同一孔內에 時差를 가진 M / S 雷管을 3, 4個씩 段階別로 裝藥하여 試驗發破한 結果, 폭원으로부터의 거리(D, m) 遲發當 최대 장약량(W, kg) 최대 진동변위속도(V, cm / sec) 사이에는 다음과 같은 부지상수를 갖는 經驗式을 얻었다.

① $V=41(D/\sqrt[3]{W})^{-1.41}$ $30^m \leq D \leq 100^m$
(R=0.69)

② $V=124(D/\sqrt[3]{w})^{-1.66}$ $100^m \leq D \leq 286^m$
(R=0.782)

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