On the vibration influence to the running power plant facilities when the foundation excavated of the cautious blasting works.

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露天堀鑿에서 發破振動의 크기를 減量 시키기 爲한 精密破實驗式

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〔要　約〕

發破에 의한 地盤振動의 크기는 火藥類의 種類에 따른 火藥의 特性, 裝藥量, 起爆方法, 塡塞의 狀態와 火藥의 裝塡密度, 自由面의 數, 爆源과 測点間의 距離 및 地質條件 등에 따라 다르지만 地質 및 發破條件이 同一한 경우 特히 測點으로부터 發破支點 까지의 距離와 遲發當 最大藏藥量 (W)간에 깊은 函數關係가 있음이 밝혀졌다.

即 發破振動式은

$$V=K\cdot\left(\frac{D}{W^b}\right)^n \quad\cdots\cdots (1)$$

여기서　V ; 振動速度, cm/sec
D ; 爆源으로부터의 距離, m
W ; 遲發　裝藥量, kg
K ; 發破振動 常數
b ; 裝藥指數
n ; 減衰指數

이 發破振動式에서 $b=\frac{1}{2}$인 경우 즉 $D/\sqrt{W}$를 自乘根 換算距離(Root scaled distance), $b=\frac{1}{3}$인 경우 즉 $D/\sqrt[3]{W}$를 立方根換算距離(Cube root scaled distance)라 한다.

이 裝藥 및 減衰指數와 發破振動 常數를 求하기 위하여 任意距離와 裝藥量에 대한 振動值를 測定, 重回歸分析(Multiple regressional analysis)에 의해 一般式을 誘導하고 Root scaling과 Cube root scaling에 대한 回歸線(regression line)을 求하여 회귀선에 대한 適合度가 높은 쪽을 擇하여 比較, 檢討하였다.

위 (1)式의 兩邊에 log를 取하여 linear form(直線型)으로 바꾸어 쓰면 (2)式과 같다.

$$\log V=A+B\log D+C\log W \quad\cdots\cdots (2)$$

여기서,　$A=\log K$
$B=-n$
$C=bn$

(2)式은 다시 (3)式으로 表示할 수 있다.

$$Y_i = A + BX_{i1} + CX_{i2} + \varepsilon_i \quad \cdots\cdots (3)$$

여기서, X_{i1}, X_{i2} ; 두 獨立變數 logD, logW의 i번째 測定値.

Y_i ; (X_{i1}, X_{i2})에 대한 logV의 測定値

ε_i ; error term 이다.

(3)式에서 n個의 資料를 (2)式의 回歸平面으로 代表시키기 위해서는 $S=\sum_{i=1}^{n}\{Y_i-(A+BX_{i1}+CX_{i2})\}^2$ 을 最小로하는 A, B, C 값을 求하면 된다. 이 方法을 最小自乘法이라 하며 S를 最小로 하는 A, B, C의 값은 (4)式으로 表示한다.

$$\frac{\partial S}{\partial A}=0,\ \frac{\partial S}{\partial B}=0,\ \frac{\partial S}{\partial C}=0 \quad \cdots\cdots (4)$$

위式을 Matrix form으로 簡單히 나타내면 式(5)와 같다.

$$\begin{vmatrix} n & \sum X_{i1} & \sum X_{i2} \\ \sum X_{i2} & \sum X_{i1}^2 & \sum X_{i1}-\sum X_{i2} \\ \sum X_{i2} & \sum X_{i2}X_{i1} & \sum X_{i2}^2 \end{vmatrix} \cdot \begin{vmatrix} A \\ B \\ C \end{vmatrix} = \begin{vmatrix} \sum Y_1 \\ \sum X_{i1}Y_i \\ \sum X_{i2}X_i \end{vmatrix} \quad \cdots\cdots (5)$$

資料가 많아 計算過程이 복잡해져서 本實驗의 測定資料들은 電算機를 使用하여 處理하였다.

root scaling과 Cube root scaling의 경우 각각

$$\left.\begin{array}{l} \log V = A + B(\log D - \frac{1}{2}\log W) \\ \log V = A + B(\log D - \frac{1}{3}\log W) \end{array}\right\} \quad \cdots\cdots (6)$$

으로 (2)式의 特別한 形態이며 log－log 座標에서 直線으로 表示되고 이때 A는 切片, B는 기울기를 나타낸다.

• 測定値의 檢討

本 資料의 特性을 比較, 檢討하기 위하여 지금까지 發表된 國內의 몇몇 資料를 보면 다음과 같다.

勿論, 裝藥量, 爆源으로 부터의 距離등이 相異하지만 大體的인 傾向性을 推定하는데 參考할수 있을 것이다.

今般 總實測資料는 總 88個이지만 換算距離(S.D)와 振動速度의 크기와의 關係에서 差異를 보이고 있어 便宜上 爆源과 測點地點間의 距離에 따라 100m 末満인 A地域과 100m 以上인 B地域으로 區分하였다.

한편 A地域의 資料 56個中, 上下로 偏差가 큰 19個를 除外한 37個 資料와 B地域의 29個中 2個를 除外한 27個(88個 資料中 距離表示가 안된 12月1日의 資料 3個는 원래부터 除外)의 資料를 computer로 處理하여 얻은 發破振動式은 다음과 같다.

$$V=41(D/\sqrt[3]{W})^{-1.41} \quad \cdots\cdots (7) \quad (-100m)$$
(R=0.69)

$$V=124(D/\sqrt[3]{W})^{-1.66} \quad \cdots\cdots (8) \quad (+100m)$$
(R=0.782)

式(7) 및 (8)에서 R은 求한 直線式의 適合度를 나타내는 相關係數로 R=1인때는 모든 測定資料가 하나의 直線上에 表示됨을 意味하며 그 값이 낮을수록 資料가 分散됨을 뜻한다.

본 報告에서는 相關係數가 自乘根 距離때 보다는 立方根일때가 더 높기 때문에 發破振動式을 立方根 $(D/\sqrt[3]{W})$으로 表示하였다.

特히 A地域에서는 R=0.69인데 比하여 爆源과 測點地點間의 距離가 100m 以相으로 A地域보다 멀리 떨어진 B地域에서는 R=0.782로 比較的 높은 값을 보이는 것은 振動成分中 高周波成分의 相當量이 減衰를 당하기 때문으로 생각된다.

Abstract

The cautious blasting works had been used with emulsion explosion electric M /S delay caps. Drill depth was from 3m to 6m with Crawler Drill *ϕ70mm on the calcalious sand stone*(soft-moderate-semi hard Rock). The total numbers of test blast were 88. Scale distance were induced 15.52-60.32. It was applied to propagation Law in blasting vibration as follows.

Propagtion Law in Blasting Vibration

$$V=K\left(\frac{D}{W^b}\right)^n$$

were
V : Peak partical velocity(cm /sec)
D : Distance between explosion and recording sites(m)
W : Maximum charge per delay-period of eight milliseconds or more(kg)
K : Ground transmission constant, empirically determind on the Rocks, Explosive and drilling pattern ets.
b : Charge exponents
n : Reduced exponents

where the quantity $\frac{D}{W^b}$ is known as the scale distance.

Above equation is worked by the U.S Bureau of Mines to determine peak particle velocity. The propagation Law can be catagorized in three groups.

Cubic root Scaling charge per delay
Square root Scaling of charge per delay
Site-specific Scaling of charge per delay

Plots of peak particle velocity versus distoance were made on log-log coordinates. The data are grouped by test and P.P.V. The linear grouping of the data permits their representalion by an equation of the form :

$$V=K\left(\frac{D}{W^{\frac{1}{3}}}\right)^{-n}$$

The value of K(41 or 124) and n(1.41 or 1.66) were determined for each set of data by the method of least squores. Statistical tests showed that a common slope, n, could be used for all data of a given components.

Charge and reduction exponents carried out by multiple regressional analysis. It's divided into under 100m over 100m distance because the frequency is verified by the distance from blast sit-

e. Empirical equation of cautious blasting vibration is as follows.

Over 30m ——— under 100m ········· $V=41(D/\sqrt[3]{W})^{-1.41}$ ·················· A

Over 100m ··· $V=121(D/\sqrt[3]{W})^{-1.66}$ ·················· B

where ; V is peak particle velocity in cm/sec D is distance in m and W, maximum charge weight per day in kg

K value on the above equation has to be more specified for further understaring about the effect of explosives, Rock strength. And Drilling pattern on the vibration levels, it is necessary to carry out more tests.

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

1. Introduotion

Explosives are widely used to break rock in mining, quarrying and civil applications. 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 speclal attention to the examination and minimizing of unwanted structural damage due to blasting. The level and oharacteristics of the empirical equations depend on many factors as rock type, geology of the area, quantity and kind of explosives, flring methods and blasting patterns etc. Variation in these faotors 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 vibration monitor with triaxial velocity transducer was used to record and measure the particle velocity. The natural frequency of vibration monitor is 5 to 200Hz with in the range of the blasting frequency.[6]

The particle velocity was calculated as the vector sum of the three traces on the chart paper corresponding to longitudinal, vertical and transverse components of the ground motions at any given time. The maximum value of this vector sum was 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 velocities.

2.2 Site conditions and Experimental Procedures

The blasting have been done with emulsion explosive(Kovex), electric milli-second delay caps. The hole with 75㎜ diameter, from 3 to 6m depth, was drilled with crawler drill and the bench out was adopted. The rocks ard calcarious sandstone(moderate-semi hard rock).

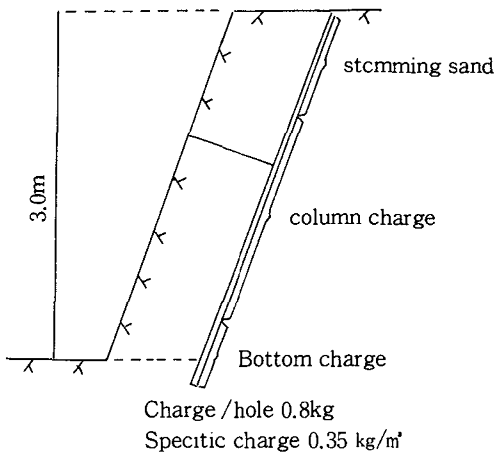

Fig.1 Drilling pattern

From 84 blasts, 55 blasts were monitored at distance of 30-98m(A zone), the other 29 blasts were also monitored 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 soale 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)			No of M/S caps(pcs)		Scaled Distance		Remarks
				Per hole	Total	Max delay	Per hole	Total	b=1/2	b=2/3	
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	5.0825	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	

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=2/3	
17	16	4.5	64	2.25	36	2.25	4	64	42.67	48.81	
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	1.16875	81.0	3.375	2	40	34.84	42.63	
48	16	6.0	55.5	5.0625	33.75	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	48.9375	3.375	2	58	35.38	43.35	
53	16	4.5	62	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 zon
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	25.8325	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	

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=2/3	
62	65	4.5	109	5.0625	329.0625	20.8125	4	260	23.89	39.55	
63	65	4.5	101.5	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	
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	

Table 2. Vibration Record

	TRAN	VERT	LONG			TRAN	VERT	LONG	
PPV	6.201	3.225	2.853	mm/s	PPV	4.093	2.853	5.333	mm
FREQ	>100	51	64	hz	FREQ	73	51	37	hz
TIME	388	387	659	ms	TIME	224	71	796	ms
ACCEL	0.42	0.18	0.11	9	ACCEL	0.23	0.18	0.27 9	
PK DISP :					PK DISP :				
1/4WAVE	0.019	0.011	0.009	mm	1/4WAVE	0.011	0.010	0.019	mm
TOTAL	0.075	0.080	0.062	mm	TOTAL	0.077	0.088	0.081	mm

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 :

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

where, V : peak partiole velocity (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 regression method and n are constants associated with a given site.

In an attempt to predict the ground vibration from blasting 85 vibration recordings were analyzed. Peak particle velocity was plotted directly against 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 to blast and site to site. Therefore considerable scatter in measurements is expected.

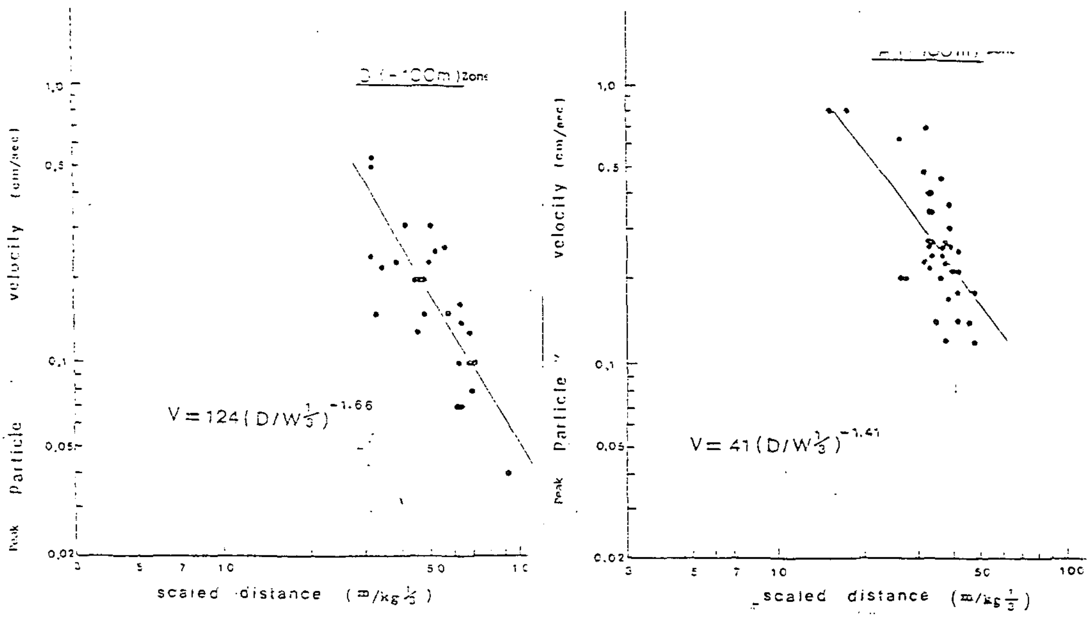

Fig.2 scaled distance vs peak particle velocity

3.2 Explosive type

Our previous studles[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, because 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 characteristlos of some explosives whioh 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	260-280
Weight(gr)	112.5	150
N.G(%)	64-66	
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 effeotive 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.

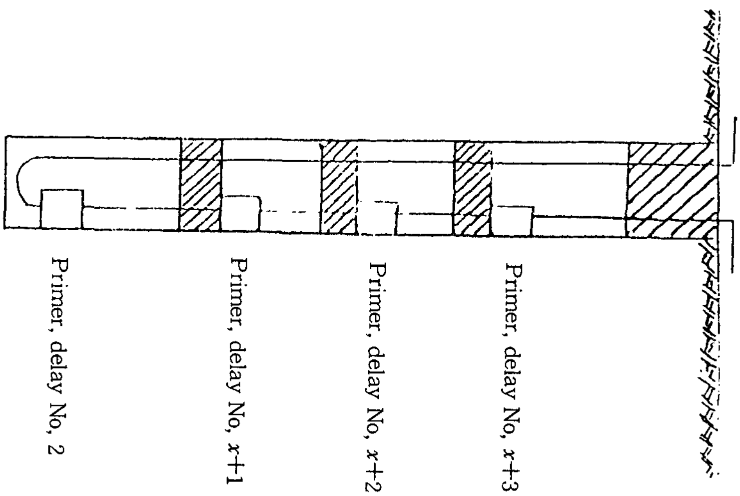

Fig.3 Deck charging of shothole with initiation of eack deck on seperate delay period.

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 frequencles in a more limited range. The relatively large explosives produced by surface mining tend 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.

Table 3. Comparison of some empirical equations in Korea

Site	Dongyang cement quarry(7)	Ssang yong Donghae cement Quarry (3)	Seoul metrosubway corp (1)	S area project
Kind of rock	limestone	limestone	Granite & Gneiss	Calcarious sandstone
Sc(kg/㎠)	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 : getine)	ANFO (primer : gelatine)	Gelatine,ammonium dynamite, slurry	Kovex
delay charg(kg)	50-472.5	723-5920	0.1125-7875	2.25-23.625(A zone) or 4.5-33.75(B zone)
distance(m)	95-679	331-2214	under 30	30-93(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	1.5-1.72, 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

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.

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

$V = 41(D/\sqrt[3]{W})^{-1.41}$ (distance : 30-93m)

$V = 121(D/\sqrt[3]{W})^{-1.66}$ (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 daopting three or four stage deck charging ; third by using 9 milli-second——25 milli-seconds electric caps.

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