〈論　文〉

都心地 發破에서 發破振動値의 크기에 影響을 미치는 諸要素

Some factors affecting level of blasting–induced vibration in urban area.

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要　旨

서울 地下鐵 3, 4號線은 고층빌딩, 各種 상점및 文化財등이 位置하고 있는 都心地를 통과하기 때문에 發破로 인한 地盤의 진동이 이들 施設物 및 人體에 큰 영향을 미치고 있다.

따라서 地盤 振動으로 因한 피해를 防止하기 위하여 發破진동値의 크기를 予測하고, 또 주어진 限界値內에서 지반당 최대 장약량을 산정함으로써 施設物의 피해 防止와 아울러 効果的인 施工을 도모토록 하는데 本 연구의 目的이 있다.

이를 위하여 3, 4號線 建設 예정지를 自由面의 數에 따라 1) 오픈컷트 工法에서 바닥파기, 2) 오픈컷트 공법에서 계단發破, 3) 턴널의 心抜發破, 4) 심발 발파후의 턴널발파등으로 나누고,

한국에서 생산되는 爆薬中 제란틴, 초안폭약, 함수폭약을 위 4가지 조건과 岩質이 서로 다른곳 10個 地域을 선정하여 試驗發破를 하면서 Sprengneter, VME, Rion 등 진동 測定機로 測定하여, 다음과 같은 結果式을 구하였다.

$V=K(D/Wb)^{-n}$에서

n 및 k는 各各 1.60～1.78, 48～138이다.

따라서 위 結果式을 이용하여 현장에서 쉽게 장약량등 발파方法을 결정할 수 있도록 nomogram 등을 제시하였다.

以上의 연구 結果를 토대로 効果的인 건설을 할 수 있었기에 今般 그 內譯을 發表코저 한다.

ABSTRACT

The blasting to construct subways in Seoul, Korea, have often increased complaints of ground vibration. In order to prevent the damage to structures, it was necessary to predict the level of blasting induced vibration and to determine the maximum charge weight per delay within a allowable vibration level. A total of 109 blasts were recorded at ten sites. Blast－to－structure distances ranged from 8 to 84. 2 meter, where charge weight varied from

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0,1125 to 7.85 kg per delay. The data from blast were studied to determine the effect of explosives type on the vibration constants(k) . Vibration constants were also analyzed in terms of compressive strength of rock and blasting patterns.

INTRODUCTION

Some mechanized equipments such as tunnel boring machine (T.B.M) has been used to construct tunnel in Korea but explosives are usually used for rock fragmentation in mining and civil. The blasting works in urban area have recently increased complaints of ground vibrations, fly rock and air blasts.

The 3rd and 4th subway line in Seoul pass through the metropolitan area, having high buildings, large shopping centers and historical treasures. The distance from blasting site to structures was generally within 40 meter and even below 14m from cultural treasure site. In order to prevent the damage to structures, it was necessary to minimize the blasting vibrations. Many empirical equation on blasting—induced ground vibrations have continuously been published by United States Bur. of Mines(U.S.B.M.) and many other researchers. The level and characteristics of the empirical equations depends on many factors such as rock type, geology of the area, quantity and type of explosives and blasting patterns. Variations in these factors produce different results and they must be taken into account to make the best empirical equations.

A total of 109 blasts were recorded at ten sites under different conditions. Using these data some empirical vibration equations appropriate to each location around subway line could be established. Among the various factors the influnce of blasting patterns, rock strength and type of explosives on the level of blasting vibratin was mainly studied. It also described some of experience encounted in subway construction at relatively shallow depths.

SUBWAYS IN SEOUL

Seoul, with more than 10 million people, is one of the most populated cities in the world. The 3rd and 4th subway line in Seoul cross each other and run north—south direction, passing through the metropolitan areas. After completing the construction, Seoul has 120. 6 Km subway lines in total length and capable of transporting 5 millon passengers per day at 3 to 7 minute intervals.

It is also estimated that about forty percent of the total traffic population of Seoul is moved by subway lines, thirty—two percent by buses and twenty—eight by other means of public transportation.

Seoul is also to construct another more four subway lines in the near future. The four lines under plan are 5th line of 12 km, 6th of 13km, 7th of 14.5km. and 8th of 19km.

PHYSICAL PROPERTIES OF ROCK

The geology of the construction areas is mainly composed of precambrian gneiss as the base rock, intruded by jurassic granite and overlain by alluvium as an unconformity. The quality of base rock and thickness of alluvium are severely changed from location to location.

The detailed geologic conditions were surveyed to know the rock quality, the direction and openness of joint, the extent of ground water inflow and the bedding planes of the strata etc.

The results will not be described here.

(1) Physical properties of rock

The velocity and the frequencies of a vibration generated by a detonation in rock mass depend on the type of used explosives, the type of blasting and especially on the elastic, physical and mechanical properties of the rock that transmits the vibration.

The detailed of rock properties are given in Table 1.

Table 1. Physical and mechanical properties of rocks

Location	Rock type	Specipeic gravity(gr)	Wave velocity(km / sec)		Compressive strength(MPa)	Tensile strength(MPa)	Young's modulus(×10)	Poisson's ratio	Schmidt hardnese
			P-wave	S-wave					
A	gneiss	2.67	5.9	2.0	85	1.5	7.65	0.14	39
B	granite	2.53	3.8	2.1	35	3.5	1.9	0.21	29
C	grnaite	2.56	4.2	2.3	78	8.2	3.4	0.24	37
D	granite	2.53	4.6	2.5	123	11.0	4.2	0.29	44
E	gneiss	2.72	4.9	2.7	38	2.7	1.8	0.24	29
F	granite	2.55	4.0	2.0	88	6.2	2.8	0.32	37
		2.57	4.9	2.6	12	2.4	2.4	0.2	43
G	granite	2.57	4.9	2.6	145	11.0	3.5	0.22	50
H	granite	2.54	3.9	2.2	39	2.7	0.7	0.17	23
I	granite	2.49	3.4	1.8	15	2.5	0.55	0.22	14
J	gneiss	2.68	4.6	2.6	140	17.5	2.35	0.27	45
K	granite	2.63	3.2	2.3	14	2.1	0.6	0.31	14

Symbols :

A ; Bakseog gogae. B ; Hongeundong. C ; Jangchungdong
D ; Keumhodong E ; Woomindong. F ; Miari
G ; Samsungyo. H ; Toegyero. I ; Toegyero
J ; Dongjadong. K ; Seoul station

Rock samples were obtained from in-situ rock and prepared as cylindrical cores of 42mm inner diameter.

The relations between Schmidt rebound hardness, P-wave velocity and uniaxial compressive strength could be represented by the following equations.

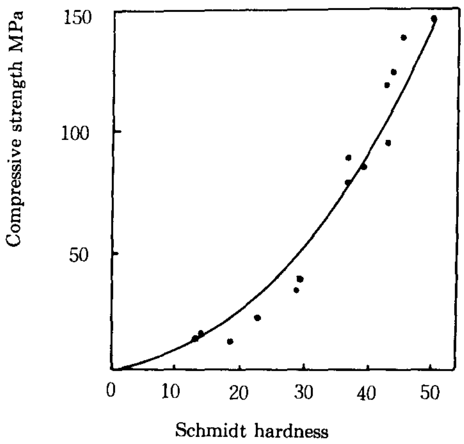
$Sc = 0.0514 \times (S.H)^{2.03}$; (1)

where Sc ; Uniaxial compressive strength (MPa)

S.H ; Schmidt rebound hardness

Fig.1 and Fig.2 are shown the these relations.

If the value of Schmidt rebound hardness for in-situ rock is known, the compressive str-



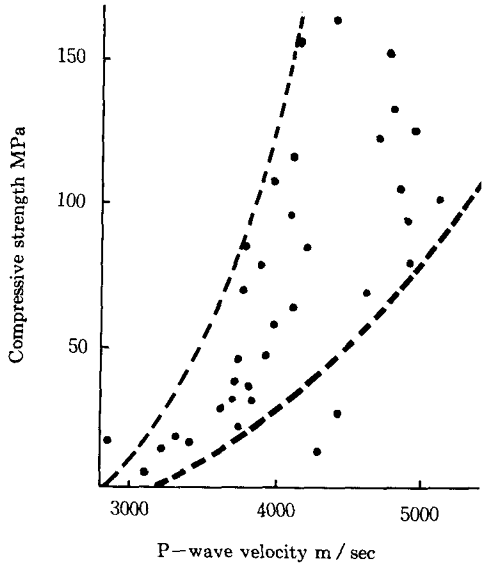


Fig. 1 Relation between compressive strength and Schmidt rebound

Fig. 2 Relation between compressive strength and P—wave velocity

ength could be approximately estimated.

No definite trend is apparent between P-wave velocity and compressive strength. However, the velocity trends to increase with the compressive strength.

(2) Classification of rock

After evaluating the blasting conditions such as strength of rock, discontinuities in rock mass and the least resistance length, the rocks at construction areas could be classified into five catagories such as hard rock, semi-hard, soft, weathered and silt.

Table 2 shows the drilling pattern and support method of tunnel due to rock conditions.

PREDICTION OF GROUND VIBRATION

Geologic conditions such as strength of rock, the degree of weathering and type of lineation have influnce on wave propagation.

Similar investigations were conducted in the same rock over a certain area to determine whether amplitudes and attenuation rates were related.

(1) Propagation of vibration.

In general, the propagation law has the form ;

$V=K.(D/W^{b})^{-n}$;(2)

where V ; peak partical velocity (P.P.V.)

K ; peak partical velocity intercept.

D ; distance from blast-to-structure.

Table 2. Classification of rocks and working pattern

Items	I	II	III	IV	V
Rock condition	stable	moderately jointed, hard stratified. schistose.	fractured, friable	unstable plastic, & squeezing	highly plastic, squeezing & swelling ground
Sc(MPa)	120−90	90−60	60−30	under 30	
Least resistance (w, cm)	60	65	70	80	
Drilling pattern	full−face	top heading & bench	top heading & bench	line drilling(pilot drift & bench)	for pilling (pilot drift)
Supporting method	occasionally rock bolt	S.C, W.M. systematic R.B for cap	S.C, W.M. R.B for cap & wall	S.C, W.M, R.B & steel rib	S.C, W.M, F.P steel lagging & S.C invert

Symbols, S.C : shotcrete
W.M : wire mesh
R.B : rock bolt
F.P : for pilling

W : charge weight per delay.
b and n : exponents

According to extensive research carried out by U.S.B.M. and many other researchers, the propagation laws can be catagorized in three groups.

ⓐ cube root scaling of charge per delay
ⓐ square root scaling of charge per delay
ⓐ site−specific scaling of charge per delay

(2) Instrumentation

The three type of seismograph, Sprengnether (V.S.−1200), Nitroconsult co(V.M.E.), and Rion(V.M.−12B) were used to record and measured the P.P.V. The former was manily used and the latter two were auxiliary used. Three used portable seismographs were calibrated in accordance with the objectives of this study.

(3) Experimental procedures and results

Prior to major blasting, a total of 109 blasts were detonated at ten sites to establish some empirical equations. Blast-to-structure distance ranged from 8 to 84.2 meter, while charge weight varied from 0.1125 to 7.25 kg per delay. The types of used explosives were gelatine dynamite, ammonium dynamite and slurry explosives which were produced in Korea.

The blasting patterns have been divided into four kinds, open cut by bottom blasting (B.T.), open cut by bench blasting (B.H.), tunnel center cut (T.C.) and tunnel cut by caving blasting (T.B.).

Table 3. Results of measuring blast−induced ground vibration and corresponding site constants

Site	Rock type	Sc(MPa)	Blasting type	Used explosive	$V=K(S\ D)^{-n}$ K	n
B	granite	35	T.C	S.E	60	1.72
			B.T	G.D	94	1.64
C	granite	78	T.C	G.D	85	1.70
			B.H	S.E	58	1.70
			B.H	A.D	47	1.70
D	granite	123	B.H	G.D	93	1.70
F	granite	88	T.C	G.D	90	1.67
		120	B.H	G.D	99	1.72
		120	B.H	S.E	76	1.72
G	granite	145	B.T	G.D	138	1.60
			B.T	S.E	107	1.63
H	granite	39	T.C	A.D	48	1.54
A	gneiss	85	T.C	G.D	56	1.50
J	gneiss	140	B.T	G.D	87	1.50
			B.H	G.D	49	1.50

Symbols : S C : Co)mpressive strength
S.D : Scaled distance
G.D : Gelatine dynamite
A.D : Ammonium dynamite
S.E : Slurry explosive
site B.C.········ J are same as Table 1.

Table 3 shows results of measuring blast-to-induced ground vibration and corresponding site constants. Empirical methods have been used to estimated value of b and n.

The measured data showed that cube root scaled distance was most applicable to this study. The typical vibration constants are estimated to be 1.60 to 1.78 for n and 43 to 138 for k in the granite base, while 1.5 for n and 17 to 87 for k in the gneiss base.

Fig.3 shows also an example of the scaled distance for blasting vibration.

INFLUENCE OF BLASTING PATTERN, ROCK STRENGTH AND TYPE OF EXPLOSIVE ON THE LEVEL OF VIBRATION CONSTANT (K).

It is well known the characteristics of the empirical equations depend on many factors such as quantity and type of explosives, blasting patterns, geology and strength of rock.

(1) Effect of explosive type for vibration constant.

Because the value of n at same condition is equal ($n1=n2$), the comparison of vibration constants among different explosives could be represented by the following equation.

$$\frac{Vs.e}{Vg.d}=\frac{K1(S.D)}{K2(S.D)}=\frac{K1}{K2} \quad ;(3)$$

where V s.e, V g.d ; P.P.V for slurry and gelatine dynamite respectively

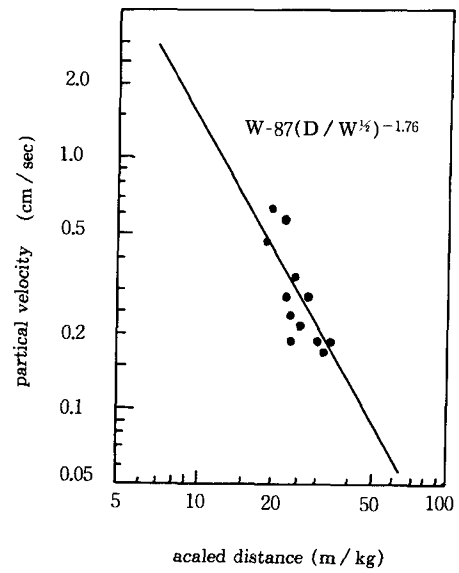


Fig. 3 Partical velocity v.s scaled distance

S.D : scaled distance (D / W^b)

K1, K2 : P.P.V intercept for slurry and gelatine dynamite respectively

Table 4 shows comparison of blasting vibration constants among explosives. Based upon the data of Table 4, the ratio(r) of slurry to gelatine dynamite appear to be 0.78, 0.76, 0.5 6 and 0.74. and those of ammonium to slurry explosive 0.81, 0.71, 0.75.

The recommended safe value of the ratio is approximately 0.80 and 0.65($0.78 \times 0.81 = 0.65$). Vibration constants could be corrected for gelatine dynamite.

Table 5 shows also corrected blasting vibration constant for gelatine dynamite. In this case, corrected values are 80% for slurry and 65% for ammonium dynamite.

(2) Effect of rock strength and blasting patterns for vibration constant(k).

Vibration constants were studied in terms of compressive strength of rock and blasting patterns. Fig.4 and Fig. 5 were obtain from Table 5, which show that vibration costant (k) generally increases as compressive strength increase and represented the difference by blasting patterns.

Vibration constants could also be represented by equations 4.5.

K (T.C)=0.37 Sc+60.
K (B.T.)=0.37 Sc+80. ;(4)
K (B.H.)=0.37 Sc+50.

K (T.C.)=0.21 Sc+40.
K (B.T.)=0.21 Sc+60. ;(5)

Table 4. Comparison of blasting vibration constants among explosives

Location	Rock	Explosive	Blasting type	$V=K(SD)^{-n}$		r(ratio)
				k	n	
C	granite	slurry	bench cut	58	1.7	$\frac{kad}{kse}=\frac{47}{58}$
		ammonium	bench cut	47	1.7	
E	gneiss	slurry	bench cut	24	1.5	$\frac{kad}{kse}=\frac{17}{24}$
		ammonium	bench cut	17	1.5	
F	granite	gelatine	bench cut	99	1.7	$\frac{kad}{kgd}=\frac{76}{99}$
		slurry	bench cut	76	1.7	
G	granite	gelatine	bottom cut	138	1.5	$\frac{kse}{kgd}=\frac{107}{138}$
		slurry	bottom cut	107	1.5	
J	granite	gelatine	bench cut	49	1.5	$\frac{kse}{kgd}=\frac{26}{49}$
		slurry	bench cut	25	1.5	
		ammonium	bench cut	20	1.5	$\frac{kse}{kse}=\frac{20}{26}$
J	gneiss	gelatine	bottom cut	87	1.5	$\frac{kse}{kgd}=\frac{64}{87}$
		slurry	bottom cut	64	1.5	

Table 5. Corrected blasting vibration constants gelatine dynamite

Location	Rock type	Sc(MPa)	blasting vibration constants		
			T.C.	B.T.	B.H.
B	granite	35	75*	94	
C	granite	78	85		73**
					78*
F	granite	88	90		99
		120			95*
G	granite	145		138	
				134*	
H	granite	39	76*		
A	gneiss	85	58	(76)	
J	gneiss	140	(67)	87	49

** : corrected value of ammonium dynamite

* : corrected value slurry explosive

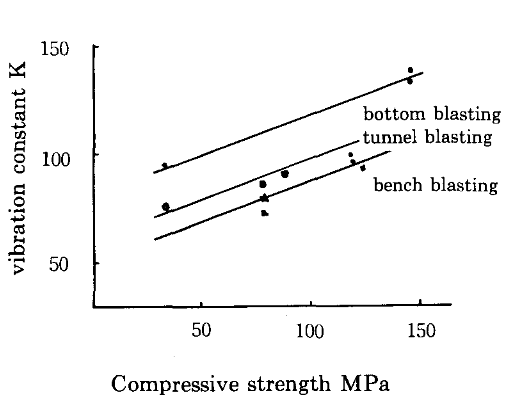
( ) : estimated value from blasting type

$$K\ (B.H.)=0.21\ Sc+30.$$

Equation 4 and 5 were obtained from granite and gneiss respectively.

CHOICE OF BLASTING PATTERNS

The construction of 3rd and 4th subway line consisted surface works of 7.7 km and underground of 48.7km. Underground works also have open cut of 33.7km and tunnel of 15.0km.



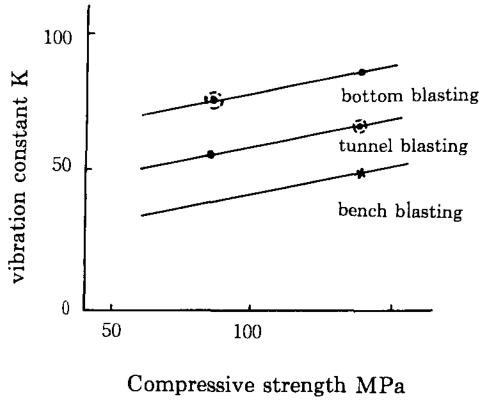


Fig. 4 Vibration constant K vs compressive strength according to blasting type in granite
Fig. 5 Vibration constant K vs compressive strength according to blasting type in gneiss.

(1) Allowable vibration value

Many reports by Langefors(1978), Edwards(1960), U.S.B.M and otehrs recommended a safe vibration level for structures .

To reduce the damage, West Germany standard as shown in Table 6 was adopted as the allowable vibration values in Seoul.

(2) Calculation of maximum allowable charge weight

If blasting conditions such as kind of rock, strength, the nearest distance to structure, allowable vibration value and type of blasting were given, the maximum charge weight per delay can be calculated by Table 4 and Table 7. In equation 2, n is 1.7 or 1.5 for granite, gneiss respectively. k can also be obtained from Table 7.

Table 7 shows vibration costants(k) in accordance with explosives and blasting patterns and compressive strenth.

Because of the scatter of the experimental data and the requirement to keep vibration levels at below the allowable limit, it is important to know the maximum probable partical velocity.

(3) Blasting patterns

Based on studies of obtained data, it is possible to decide the blasting patterns appropriate to each locations.

Some used blasting pattens can be classified as follows :

Tunnel blasting : full−face blasting
top heading & bench blasting
partial blasting
Open-cut blasting : H pile
New Austrian Tunneling Method(N.A.T.M)
Controlled blasting : line drilling pre-splitting smooth blasting

Table 6. Allowable value of blasting vibration

classification	vibration value on ground (cm / sec)
cultural treasure	0.2
Housing,apartment with partial crack	0.5
shopping center	1.0
Factory & reinforced concreate building	1.0~4.0

West Germany vornorm, DIN 4150, Teil 3

Table 7. Vibration constants k in accordance with explosives and blasting patterns

Explosives	Blasting patterns / Sc (MPa)	open cut O.T	open cut O.B	tunnel cut T.C	tunnel cut T.B
gelatine dynamite	180−150	147	117	127	97
	150−120	138	106	115	86
	120− 90	125	95	105	75
	90− 60	114	84	94	64
	−60	103	73	83	53
slurry explosive	180−150	117	94	102	78
	150−120	109	85	93	59
	120− 90	100	76	84	60
	90− 60	91	67	75	51
	−60	82	58	66	42
ammonium dynamite	180−150	96	76	66	63
	150−120	87	68	74	55
	120− 90	80	61	57	48
	90− 60	73	54	60	41
	−60	66	46	53	34

conditions : $V=K \cdot W^{0.57} \cdot D^{-1.7}$

Seoul granite

hole diameter : 38m / m

Blasting working was planned varying the advance per round, the number of holes, quantity of explosives per hole, the spacing between holes and the diameter of hole in accordance with the maximum allowable charge weight.

The blasting patterns and N.A.T.M are well known and will briefly describe here.

ⓐ In the tunnel blasting or open patterns, the cut holes were initiated with milli-second delays instead of instantaneous detonators. This was done to take advantage of the scatter in delay times.

ⓐ To reduce blasting vibration, N.A.T.M was adopted for fractured or unstable pastic rock. Some characteristics of N.A.T.M can be said to be regular performance of safety inspections, include of measuring surface subsidence,sidewall deformation state, compressive and tensile strength of soil, underground displacement and so on. The safety inspections have been measured by the use of load cell, convergence meter, extensometer and inclinometer.

ⓐ For preventing over excavation, and reducing the damages on rock beds and the level of blasting vibrations as much as possible, the control blasting of line drilling, presplitting and smooth blasting have been employed.

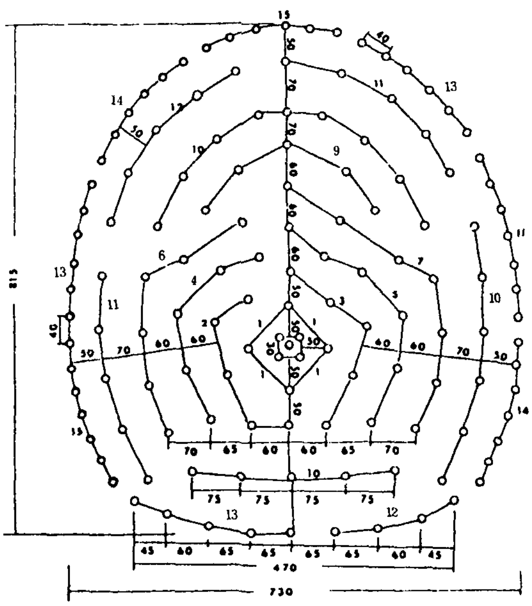
ⓐ The line drilling was used when the shortest distance between the blast-to-structure was 10 m or less. By this way no back break would caused structures to fall. To reinforce the remaining rock, injections or shotcreating were sometimes used.

ⓐ Smooth blasting and pre-splitting methods utilized a de-coupled charge in order to keep the borehole pressure low.

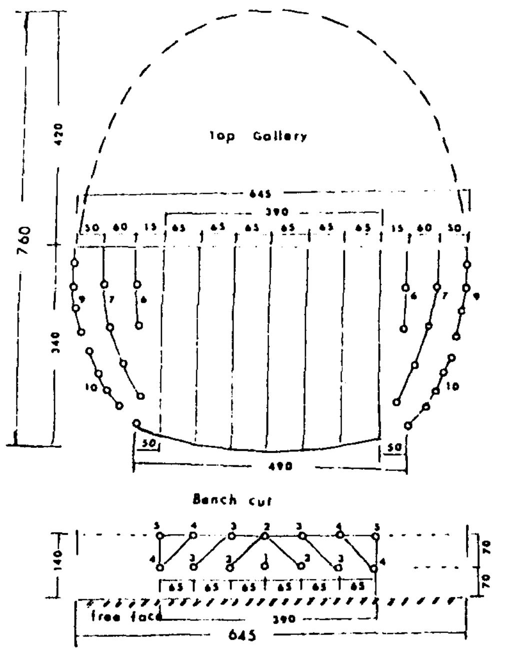
ⓐ Pre-splitting is to make a vibration proof barrier by firing a series of holes drilled on the wall in advance of main blasting, while smooth blasting is to fire from cut holes to the holes at both sides in sequance in tunnel heading.

ⓐ The used explosives were mostly those of low spececific gravity and low velocity such as slurry, A.N.F.O. and C.C.R instead of gelatine dynamite.

ⓐ Firing were done by the use of multistage delay electric detonators and milli-second detonators instead of the electric detonators.



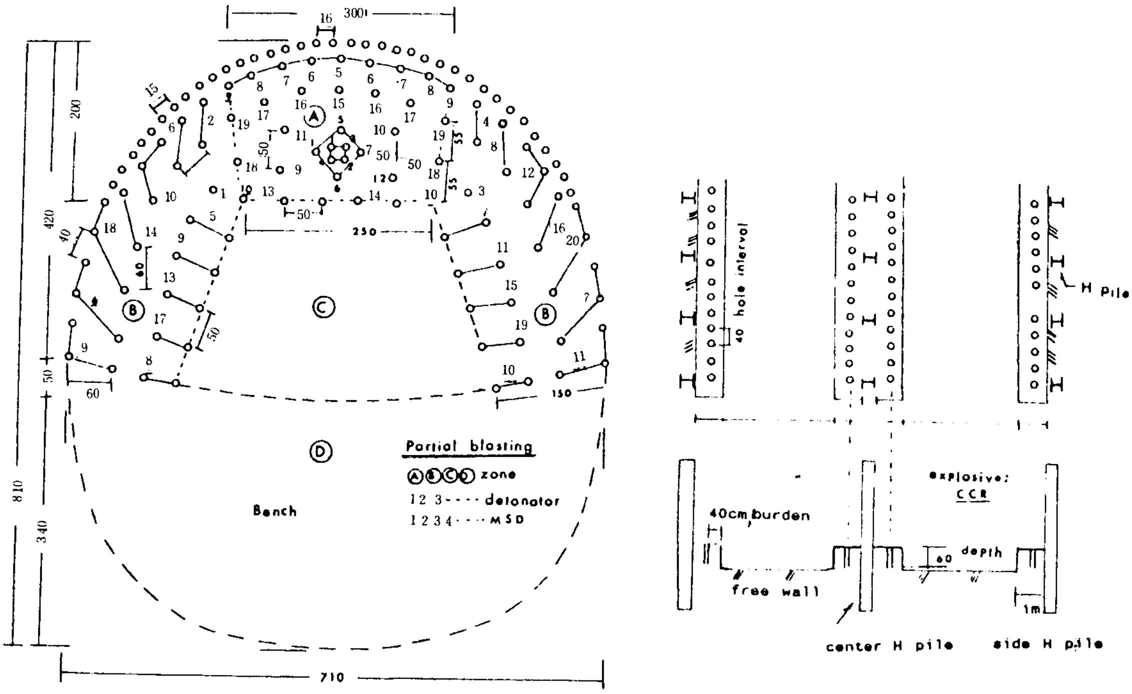
(a) full−face pattern



(b) top heading & bench pattern

Symbol. 1. 2.······19 ; order of milli−second delays

⊢50⊣ ; length between holes



(C) partial pattern (D) Pattern near H pile(in open cut)

Fig. 6 Some examples of drilling & blasting patterns

CONCLUSION

A total of 109 blasts were tested and analyzed to determine vibration equatin by empirical methods and maximum charge weight per delay within allowabel vibration level.

The results can be summarized follows ;

1. By an analysis of the measured data near Seoul subway line, cube root scaling might be more reasonable than square root scaling.

2. The vibration constants K is represented by an equation,

$K = Ei \cdot (Ri \cdot Sc + Qi)$

where Ei ; correction ratio according to explosives

Ri ; constants according to rock type

Sc ; compressive strength of rock

Qi ; correction value according to blasting type.

3. The vibration levels of ammonium nitrate and slurry explosives were smaller about 35 %, 20 % respectively than that of gelatine dynamite.

4. Using various blasting and excavation pattern such as controlled, partial blasting and N.A.T.M., 3rd and 4th line could be completed safely.

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