[論 文]

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# 서울 지하철 건설의 발파기술 발전

## ON THE DEVELOPMENT OF EXPLOSION TECHNOLOGY IN SEOUL METRO SUBWAY CONSTRUCTION

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## ABSTRACT

The blasting work to construct a subway in Seoul, Korea have often caused increased neighbor's complaints because of ground vibration.

In order to prevent the demage to the structure, it was necessary to predict the level of blasting induced vibration and to determine the maximum charge weight per delay within an allowable vibration level.

The effect of blasting pattern, rock strength and different explosives on the blast-induced ground vibration was studied to determine the maximum charge weight per delay within a given vibration level. The blasting vibration equation from over 100 test data was obtained, $V=K(D/W^{1/3})^{-n}$ , where the values for n and K are estimated to be 1.7 to 1.5 and 48 to 138 respectively. See Table 1

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Sequential blasting machine was applied to the site.

Tunneling have been working so carefully in order to decrease vibration and Noise to near shopp and housing area.

We carried out empirical formula to solve city environmental pollution as follow;

Empirical formula

For Granite : $V = KW^{0.57}D^{-1.75}$

For Gneiss : $V = KW^{0.5}D^{-0.5}$

For Concrete breaker : $V = KW^{0.5}D^{-1.75} = 7\times 0.06^{0.5}D^{-1.75}$

W = Amount of Power/delay kg

D = Distance m

V = Partical vibration velocity cm/sec

K = Coefficiency=Ei (Ri,Sc+Qi)

Sc : Compressive St. kg/㎠

Ei : Power Compensation Ratio

- Dynamite = 1
- Slurry = 0.8
- AN = 0.65

R : Rock Coefficiency

Seoul Granite = 0.0371

Seoul Gneiss = 0.0206

Q : Compensation by blasting pattern

Apply distance ; -30m

Bit Gage ; Φ 38mm

Explosive ; Emulsion

Electric caps ; M/S

Pattern ; Bench cut Tunnel

## 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 120.6km subway lines in total length and capable of transporting 5 million 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 by buses and twenty-eight by other means of public transportation.

## 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 overclean by alluvium as an unconformity. The quality of base rock and thickness of alluvium are severely changed from location to locations.

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 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 2.

Rock samples were obtaining from in-situ rock and prepare 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.

$$Sc = 0.0514 \times (S.H)^{2.3} \quad : (1)$$

where sc : Uniaxial compressive strength (MPa)
S.H : Schmidt rebound hardness

Fig. 1 and Fig. 2 are shown the relations.
If the value of Schmidt rebound hardness for in-situ rock is known, the compressive strength could be

approximately estimated.

**Empirical Formula of standard blasting test**

In case of tunnel blasting, there is only free face the tunnel heading. After the center holes were blasted, the works, which remain, is the implementation of bench cut against the opening to make the full sectional area required. The quantity of explosives to be charged, however, is hardly estimated, as rocks very seldom show any sign of homogeneous quality.

Experimental tests therefore have been implemented to calculate the specific charge of the explosives of the certain strength, the spacing of holes and the diameter of holes to be drilled.

A series of holes are drilled at 800mm behind the face to a depth of 1,200mm and firings are implemented at each hole with varied charge of explosives until the burden is teared off. Should it be realized, the specific charge of the rock to be blasted can be calculated by the following formula

$$Ca = \frac{A}{SW}$$ where as A = m activated area

S = Peripheral length of Charged room

Ca = Rock Coefficient

Di = Holes diameter

Later in 1980, the Dynamite Explosive was replaced into Emulsion & Milli-Second Delay Electric Cap.

Table 4 Standardization in tunneling

Fig. 3 Tunnel Blasting Drilling Pattern

**Production of ground vibration**

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

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

Propagation of vibration

In general, the propagation law has the form:

$$V = K (D/W^{b})^{-n} \quad : (2)$$

Where V : peak partical velocity(P.P.V)

K : peak partical velocity intercept

D : Distance from blast-to-structure

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 blasting patterns have been divided into four kinds, open cut by bottom blasting, open cut by bench blasting, tunnel center cut and tunnel cut by caving blasting.

Results of measuring blast-to-induced ground vibration and corresponding site constants. Empirical 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 b 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.

Seoul Metro-Subway Empirical formula

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Pattern ; Bench cut Tunnel

**Conclusion**

Generally speaking, the geological feature of city Seoul is largely shaped by the Han River, which flows from the east to the west. The northern area of Seoul is comprised by Seoul Granite of Jurassic period and the Southern part by Gneiss of Cambrian period.
Therefore we should be alert for the vibration and noise caused by cautious blasting works under the minus 30 meters from the surface of the shopping and housing Zones.
Gneiss and Granite are generally regarded as stable rock. However in the vicinity of rivers a partial area is composed by Fractured Rock.

First of all, by appliers Deck charge, empty line drilling, the pit of shaft construction is performed to eliminate or reduce vibration and noise.

Secondly, the tunnel pattern is based on experimental scale distance equation and crown part of tunnel face adopted pre-splitting and center cut of face also applied large bit diameter ø70mm-120mm by burn cut. So the allowable vibration value is fixed not over 0.4 kine and noise not over 80db. We gauged each fire by instantel blastmate DS 277. Thus the Seoul city sub-way construction has been executed in a satisfactory manner.

By an analysis of the measured data near Seoul subway line, cube root scaling might be more reasonable than square root scaling.
To estimate the safe charge weight easily in the field, some nomograms and tables were given.
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 with sequential blasting machine at subway tunnel works.
For further understanding about the effects of explosives, rock strength and blasting types on the vibration levels it is necessary to carry out more tests.
Nowadays, we are proud so efficiency work with Sequential Blasting machine at subway Tunnel Works but I expect to apply Mac's auto marking System at Tunnel face sooner and hope to meet Robot Drill Semi-Jumbo(13× 10 meter face) presentation in the near future.

Table 1 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 concrete building | 1.0~4.0 |

Table 2 Construction Schedule of Seoul Metro-Subway Line.

| Division | Total | Line 1 | line 2(Loop Ⅰ) | | Line 3 | Line 4 | Line 5 | Line 6 | Line 7 | Line 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main | Branch | | | | | | |
| Length in Kilometer | 278.6 | 9.5 | 48.8 | 5.3 | 27 | 30 | 55.8 | 35.2 | 47 | 20 |
| Station | 250 | 9 | 43 | 3 | 23 | 24 | 51 | 38 | 42 | 17 |
| Rolling Stokes | 844 | 96 | 272 | | 132 | 138 | 76 | 46 | 62 | 22 |
| Headway in Minute | | 3 | 3.5 | | 3.5 | 3.5 | 2.5 | 5.5 | 3.0 | 3.5 |
| Construction Terms | 71-20 | 71-74 | 78-83 | 78-83 | 80-86 | 80-86 | 96-99 | 96-20 | 96-20 | 96-99 |
| Passenger per Day in million | 5 | 1 | 1.5 | | 1.2 | 1.3 | | | | |
| Construction Status | | run | run | run | 60% | 60% | run | 80% | 80% | run |
| Construction costs in 100 million won | 23,579 | 330 | 9,440 | | 6,548 | 7,277 | | | | |

Table 3 Physical and Mechanical properties of rocks

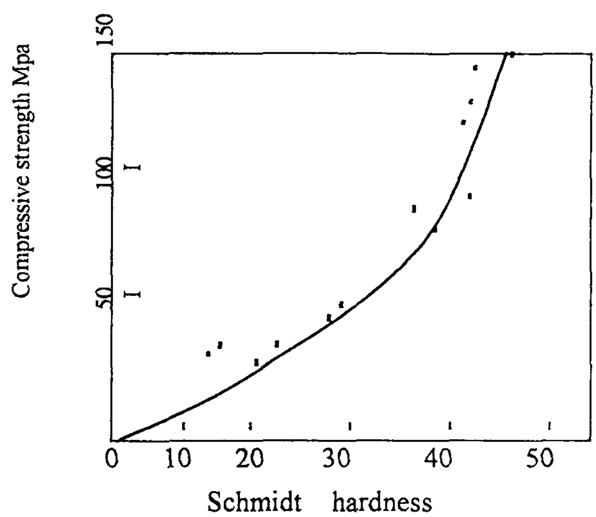
| Location | Rock type gravity(gr) | Specific gravity(gr) | Wave velocity(km/sec) | | Compressive Strength(MPa) | Tensile strength(MPa) | Young's modulus(× 10) | Poisson's ratio |
|---|---|---|---|---|---|---|---|---|
| | | | P-wave | S-wave | | | | |
| A | Gneiss | 2.67 | 5.9 | 2.0 | 85 | 1.5 | 7.65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

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

Table 4 Standardization in tunneling

| | I | II | III | IV | V |
|---|---|---|---|---|---|
| Rock / Kind | Stable rock | Moderately jointed and hard stratified or schistose | Fractured and friable rock | Unstable plastic & squeezing rock | highly Plastic squeezing & swelling ground |
| Burden (cm) Bit Gage = 38m | 60 | 65 | 70 | 80 | |
| Drilling | Full face | top heading & bench | Top heading & bench | line-drilling (pilot drift & bench) | for pilling |
| Support | Occasional 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 |

S.C = Shotcrete R.B = Rock bolt
W.M = Wire Mesh F.P. = For Pilling



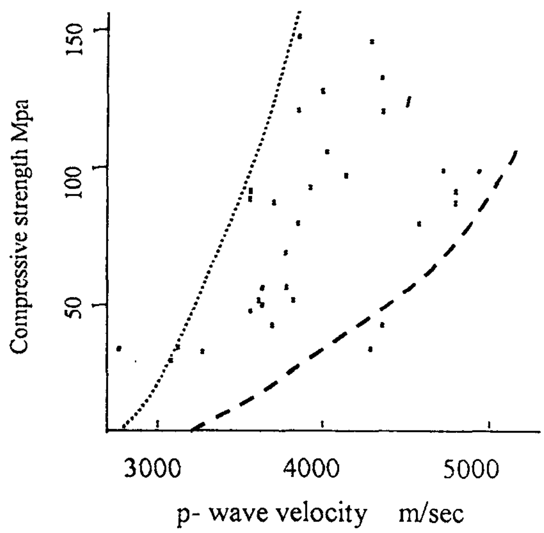




Fig. 1 Relation between compressive strength and Schmidt rebound

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

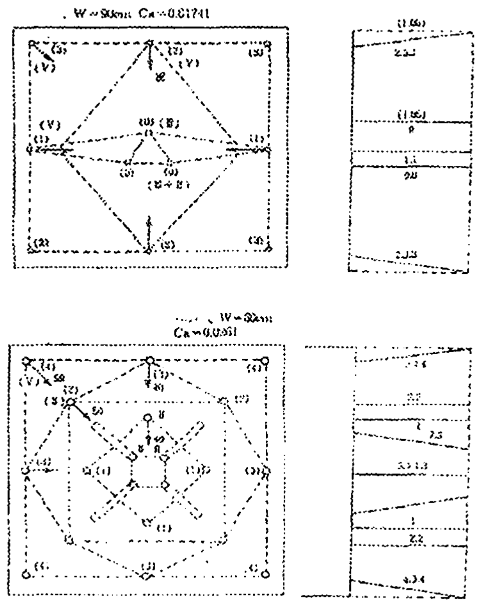


Fig. 3 Tunnel Blasting Drilling Pattern

# SEOUL -SUBWAY 6-9 SITE
## CHARGE CALCULATION
### Stable Rock

| | | | | | |
|---|---|---|---|---|---|
| DRILLED DEPTH | 1.0m | ADVANCE | 0.8 m | DETONATOR | 388 pcs |
| CHARGE | 96.515 kg | NUMBER OF HOLES | 570 m | SPECIFIC DETONATOR | 4.96PCS $m^3$ |
| TOTAL DRILLED DEPTH | 678 m | SPECIFIC DRILLED DEPTH | 8.66m/ $m^3$ | FACE AREA | 97.877$m^2$ |
| SPECIFIC CHARGE | 1.233kg/$m^3$ | EXCAVATED SOLD ROCK OF FULL FACE | 78.30 $m^3$ | | |

| Face | Round | Classification | Cap No. | No. of Holes | Amount of charge | | | | | | | Remarks (Drilled depth) m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Slurry(k-100) ϕ 25 mm X 433 mm X 250 g/pc | | F-1 ϕ 17 mm X 425 mm X 100g/pc | | F - 2 ϕ mm X mm X g/pc | | Total | |
| | | | | | Per hole | Sub -total | Per hole | Sub total | Per hole | Sub Total | | |
| | | | | Hole | PCS | PCS | PCS | PCS | PC | PCS | g | |
| (Top Gallery Right Face) A | 1 | Cut Holes | MS 1~ 4 | 4 | 1 1/3 | 5.34 | | | | | 1,335 | |
| | | Cut Spreader H. | 5~12 | 12 | 1 1/3 | 16 | | | | | 4,000 | |
| | | Stopping H. | 13~20 | 26 | 1 | 26 | | | | | 6,500 | |
| | | | DS 6~12 | 41 | 1 | 41 | | | | | 10,250 | |
| | | F-1 Line | 13~15 | 21 | 1/4 | 5.25 | 1 | 21 | | | 3,412.5 | |
| | | Stopping H. | 16~17 | 12 | 1 | 12 | | | | | 3,000 | |
| | | Foot H. | 18~20 | 12 | 1 1/3 | 16 | | | | | 4,000 | |
| | | Empty H. (cut) | - | (15) | - | - | | - | | | | Ø120mmX 2m |
| | | 空孔(stopping) | - | (53) | - | - | | - | | | | Ø120mmX 1m |
| | | Line drilling | - | (35) | - | - | | - | | | | Ø38mmX 2m |
| | | Sub Total | - | (103) 128 | | 121.59 pcs | | 21pcs | | | 32,497.5g | |
| | | | - | 231 | | 30,397.5 g | | 2,100g | | | 32.4975kg | |
| Top Gallery Left Face B | 2 | Stopping H. | MS1~20 | 76 | 1 | 76 | | | | | 19,000 | |
| | | | OS 6~9 | 19 | 1 | 19 | | | | | 4,750 | |
| | | F-1 Line | 10~16 | 36 | 1/4 | 9 | 1 | 36 | | | 5,850 | |
| | | Foot H. | 17~20 | 11 | 1 1/3 | 14.67 | | | | | 3,667.5 | |
| | | 空孔(stopping) | - | (21) | | - | - | - | | | - | Ø120mmX1m |
| | | Line drilling | - | (58) | | - | - | - | | | - | Ø38mmX 2m |
| | | Sub Total; | | (79) 142 | | 118.67 pcs | | 36pcs | | | 33,267.5g | |
| | | | | 221 | | 29,667.5g | | 3,600g | | | 33.2675kg | |
| Top gallery | | Total | | (182) 270 | | 240.26 pcs | | 57pcs | | | 65,765g | |
| | | | | 452 | | 60,065g | | 5,700g | | | 65.765kg | |
| Bench C | 3 | Stopping H. | MS1~20 | 65 | 1 | 65 | | | | | 16,250 | |
| | | | DS 6~11 | 22 | 1 | 22 | | | | | 5,500 | |
| | | F-1 Lines | 12~13 | 10 | 2/5 | 4 | 1 | 10 | | | 2,000 | |
| | | Foot H. | 14~19 | 21 | 1 1/3 | 28 | | | | | 7,000 | |
| | | Total | | 118 | | 119pcs | | 10pcs | | | 30,750g | |
| | | | | 118 | | 29,750g | | 1000g | | | 30.75kg | |
| Full Face | | Gross Total | | (182) 388 | | 359.26 pcs | | 67pcs | | | 96,515g | |
| | | | | 570 | | 89,815g | | 6,700g | | | 96.515kg | |

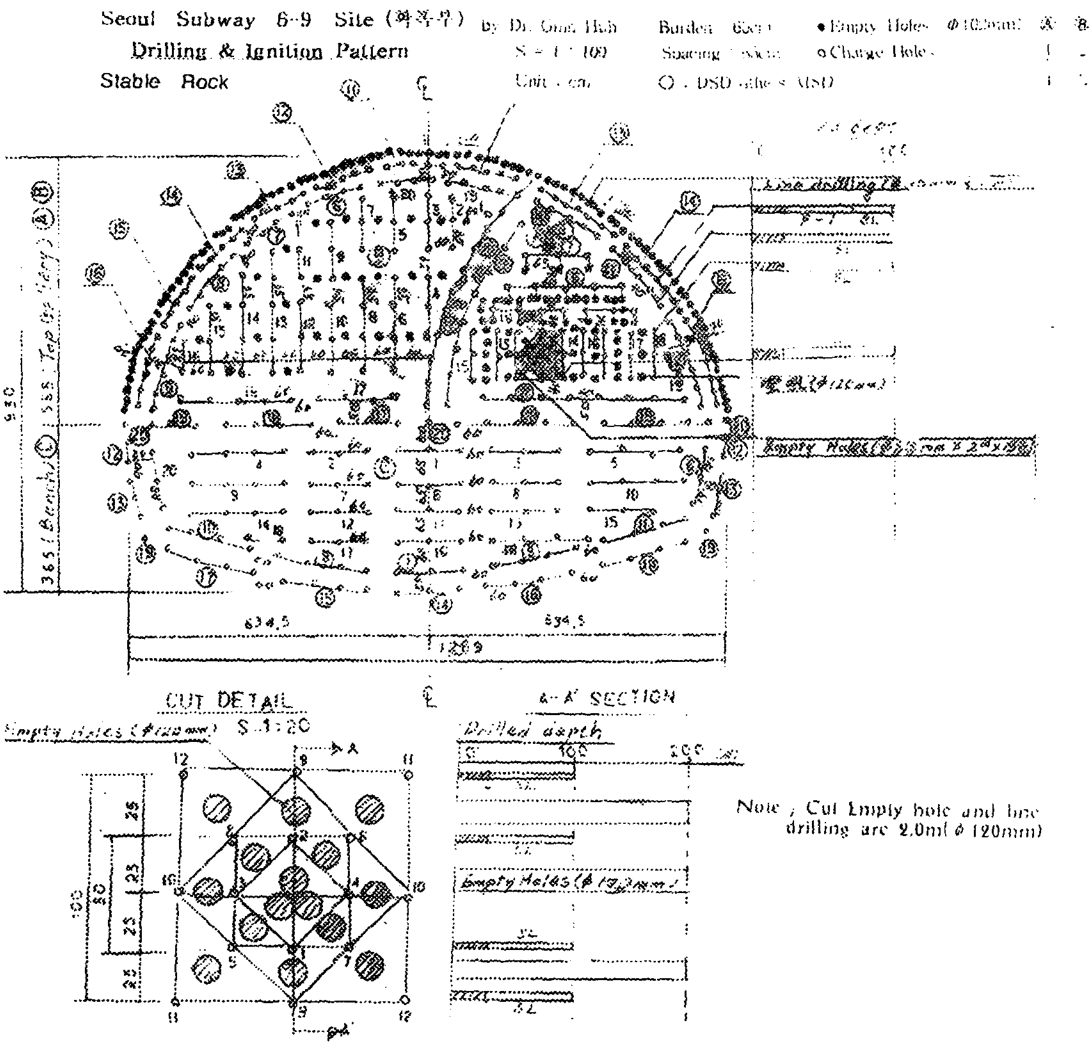



Fig 4 Pattern