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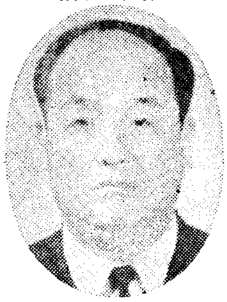

The Construction of Seoul Subway Line 3 and 4

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ABSTRACT

The traffic congestion of Seoul city has been one of the most serious problems to be settled since the advent of 1970s. As a means to mitigate traffic mess, the authority concerned launched the construction of subway line 3 and 4 in 1980.

The two Subway lines slated for completion by 1985 cross each other and run north-south direction, passing through the metropolitan area of Seoul city fraught with high-rise edifices and large-scale shopping centers, and, in order to reduce blasting vibration, NATM was executed for a distance of 10 Km, instead of ASSM previously employed when subway line 1 and 2 were constructed.

Tunnel blastings were implemented, preceded by classifying the rocks at construction area into five categories, namely, hard rock, semi-hard rock, weak rock weathered rock and silt and by calculating their respective specific charges through standard test blastings, by employing the pre-splitting and smooth blasting with drilling patterns of burn cut type, so as not to cause damages to surface structures. Most of explosives used were the slurry of low specific gravity and low velocity, and the firings executed by the use of milli-second detonators.

Empiric formula were also formulated to check blasting vibrations, based on the vibration allowable values of West Germany standard, for the application to vulnerable construction zones.

Should the two lines be placed for public service in 1985, about 40% of the total traffic population of Seoul city amounting to 15 million as of 1984 is estimated to be carried by subway with no difficulties.

1. Outline

Seoul, the capital of the Republic of Korea, is one of the most populated cities in the world, comprising 9 million people, 22 percent of national population, in an area of 627km², 0.63

* Mining, P.E. Consultant Seoul Metropolitan Subway Corporation Korea.
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percent of national territory as of 1983.

In the later half of 1950s, Seoul started sustaining traffic congestion problem and the authority concerned of Seoul city withdrew the street cars which had been under operation from the time of Japanese colonial rule, supplementing substantially urban buses, as a measure to provide seoulites with better means of public transportation.

Since the advent of 1970s, however, the measure was not efficient enough to cope with the hiking increase in traffic population. The transportation by bus futhermore caused frequent outbreaks of traffic accidents, especially on rainy days and public nuisances such as air polution and noise pollution. The authority therefore implemented systematic studies for mitigating traffic mess and became convin ced that the construction of subway would be the best to meet the purpose, as facilitating safe and speedy transportation, and reducing environmental disruption.

2. History of subway construction

Seoul city launched in April, 1971 the construction of subway line 1 connecting a distance of 9, 5 Km from Seoul railway station to Chungryang-ri located at the eastern side of Seoul. This subway line with a transportation capacity of 1 million per day has been running at 3 minute headways since completed in August 1974, but only sufficient to meet 10 percent of the transportation requirements of Seoul city.

In March, 1978, Seoul city started again constructing subway line 2, a loop line of 48 Km in total length, circulating the suburban residence area south of Han river from Seoul city hall. This subway line with a transportation capacity of 1, 5 million per day has been running at 3, 5 minute headways since June, 1984.

There are also two subway lines under construction in Seoul since 1980 ; one is subway line 3 of 27 Km lengthwise from Kupabal to Yangjae-dong and the other subway line 4 of 30 Km in length from Sangge-dong to Sadang-dong. In case these two lines are launched into operation in 1985, Seoul subways will be 120, 6 Km in total length and have 102 stations and 656 pieces of rolling stock, capable of carrying 5 million passengers per day at 3 to 7 minute headways.

It is also estimated that about 40 percent of the total traffic population of Seoul city will be transported by subway lines, 32 percent by buses and the remaining 28 percent by other means of public transportation. As of 1984, the traffic population of Seoul city increased to 14, 629, 000, of which 37. 2 percent was transported by subway, 32. 8 percent by bus and the rest 30 percent by other transportation means. The details on Seoul subway lines are shown in the Attachment 1 and 2.

3. Construction of subway line 3 and 4

3-1 Scope of works

The construction of subway line 3 and 4 comprises surface works of 7. 7 Km and underground works of 48. 7 Km, whereas surface works stands for the construction of bank, bridge and elevated structure' and undeground works the construction of open cuts (33. 7Km) and tunnels

(15.0Km).

When it comes to tunnelling, two kinds of methods have been employed such as New Australian Tunnelling Method (NATM) and American Steel Support Method (ASSM), whereas the former has been executed at the geologically weak zone of the downtown area densely populated and the latter at the suburban area less populated.

NATM, as a speedy, cost-saving and safe method of tunnelling, comprises excavation, support and measurement of deformation and displacement, of which the excavation has been carried out in accordance with the writer's technical instructions, but the support and measurement under the technical advice by Geo-Consult Co., Austria. The technology of measurement has been applied to the execution of ASSM and open-cut as well. The details on ASSM and NATM are explained in the Attachment 3 and 4.

3-2 Technical aspects related to tunnelling

Tunnel blasting has been implemented after careful study on the geology of construction site, the optimum condition of explosive charge, the propagation of blasting vibration and so on, so as not to effect over-charge and over-excavation, as it will give damages to the structures on the surface.

The geology of the construction sites is mainly composed of Pre-cambrian gneiss as the base rock, intruded by Jurassic granite and overlain by alluvium as an uncomformity. The quality of base rock and the thickness of alluvium fluctuate greatly from location and to location, ruling out the application of an uniform blasting method.

To decide the blasting pattern appropriate to each locations, geological survey reports have been reviewed and field surveys implemented, followed by the classification of the rocks at construction sites into five categories such as hard rock, semi-hard rock, soft rock, weathered rock and silt, and the calculation of their respective charge, the spacing of holes and the diameter of holes required to tear a certain burden, through carrying out the experimental tests of the Attachment 5, resulting in the standardization in tunnelling as specified in the Attachment 6. Studies have been implemented on the effects of the bedding states of geological strata on blasting as well. So to speak, the geological strata of a strike vertical to tunnel axis is easier to excavate than those of parallel and dipping direction as explained in the Attachment 7.

Subway line 3 and 4 cross each other and run north-south direction, passing through the metropolitan area of Seoul city fraught with high-rise edifices and large-scale shopping centers. Prior to executing blasting, therefore, precise calculations have been implemented on the particle vibration velocity by formulating the empirical formula as shown in the Attachment, 8, based on the vibration allowable values of West Germany standard, as presented in the Attachment 9.

As the measures for reduring the damages on rock beds and the blasting vibration as much as possible, the control blasting methods of pre-splitting and smooth blasting have been employed with the drilling patterns of burn cut type as appear in the Attachment 10, whereas the former is to make a vibration-proof barrier by firing a series of holes drilled on the bottom in advance of main blasting and the latter is to fire from center holes to the holes at both sides in sequence in tunnel heading.

The explosives used were mostly of low specific gravity and low velocity such as slurry, ANFO and CCR as listed in the Attachment 11, instead of gelatin dynamite, and the firings were done by the use of multi-stage delay detonators and mili-second detonators, instead of the electic detonators of common use. The consumptions of explosives and detonators were 86 tons and 305,000 units per month on the average respectively.

The blasting methods aforementioned, however, were not efficient enough to meet the regulations under enforcement in Korea which don't allow more than 15cm over-excavation and experiments are being carried out on the Aqua Blasting System (ABS) to attain the

3-3 Construction and safety inspection

The construction of subway 3 and 4 was slated for completion by 1985 to prepare for the 1986 Asian games and 1988 Olympic games. To attain the objectives, the whole construction area was divided into 48 construction zones of 1 to 1.2Km lengthwise and entrusted to 23 domestic firms highly reputed for their achievements at home and abroad, including the Middle East.

In the process of construction works, difficulties have arisen, because of the vulnerable foundation at metropolitan area, making it indispensable to execute NATM for an area of 10 Km, which is equivalent to 16.9 percent of the whole construction area, as specified in the Attachment 12, instead of ASSM employed when constructing subway line 1 and 2. The subway line 3 and 4 were constructed 18m deep from the surface on the average with tunnels installed at 20m depth, whilst subway line 1 and 2 are 10m and 20m deep from the surface respectively.

NATM has been executed at 17 construction zones of heavy traffic volume out of 48 construction zones, as holding the advantages of reducing traffic mess compared to ASSM previously executed, shortening construction period, as the change in surface condition doesn't enfluence any effect to the execution of works, minimizing the hindrances to the social and economic activities of near-by residents and reducing the compensation costs for the damages inflicted on surface structures.

The most important work in the execution of NATM can be said to be regular implementation of safety inspections, inclusive of measuring surface subsidence state, side-wall deformation state, compressive & tensile strength of soil, underground displacement and so on. The safety inspections have been performed fivefold by supervisor, safety engineer, inspector, inspector from the authority and inspector from construction company, by the use of load cell, convergency meter, extensometer and inclinometer as explained in the Attachment 13. In case something wrong is identified during the process of safety inspections, corrections have been made by means of grouting or other way for reinforcement, prior to taking up the next phase of works.

One of the most difficult tasks encountered during construction works was the installation of a station at the location only 14m far from the East Gate designated as national cultural trasure No. 1, which was erected 600 years ago as the gateway to enter Seoul. The installation caused one and half year delay in the construction schedule. In order to preserve this cultural asset made of wood on stone foundation, it was necessary to minimize blasting vibration, as there already existed substantial vibrations produced by the rolling stocks of subway line 1 and vehicles on the surface roadway. To achieve the objective, technical advices have been received from relevant researchers of Korea advanced Institute of Science and Technology (KAIST) on a research contract, even from the consultants of West Germany and Japan. As the result, a new blasting pattern has been designed and such vibration-proof measures taken as the installation of ballast mat under the track and vibration-proof wall.

The fluctuations in surface weather conditions such as the long spell of rain during summer and the excessive cold during winter also caused substantial delay in the construction schedule and quite a few accidents at the beginning, but this problem have been overcome by establishing water-proof measures and wintering measures.

Subway construction comprises a diversified field of engineering works including civil works, architectural works, electrial works, the installation of track, communication and signal system, and the manufacture of rolling stock. Therefore, a project monitoring management reporting system (PMRS) has been employed to enhance work efficiency and coordination, and a management information system (MIS) established to ensure maximum coordination and to rationalize project administration.

3-4 Facilities

To reduce the vibration of rolling stocks to the maximum when they are placed into public service, the rails of 20m have been welded by telmit orgas welding to take the distance between each connections 500 to 2000m long and sleeper connections made of elastic materials. The communication system has been changed to automatic train control devices from the previous total traffic control devices. To improve environmental conditions, mechanical ventilation systems have been installed istead of natural ventilation. Deep plateforms have been installed with escalator at every large stations under the technical supervision by a French architect. The kinds of equpments mobilized for this construction works are listed in the Attachment 14.

Aside from those mentioned above, computerized train controls and sytsematized signal system are installed for the benefits and security of passengers. An auto-fare collection system are also adopted to reduce manpower and to increase mobility.

Seoul Metropolitan Subway Corporation opened an international bidding for the procurement and the installation of facilities mentioned above and concluded a contract with GEC-TPL of the United Kingdom for the guarantee of every system including foreign and local facilities. Rolling stocks will be supplied from GEC-TPL, signal & communication system from WABCO of U.S.A. and electric parts from Westinghouse of U.S.A.

3-5 Construction costs

The construction costs of subway line 3 and 4 amounted to 1,579,220 million wons (1,974 million dollars), of which 185,000MW was appropriated by Government, funs, 180,000MW by bank funds, 301,500MW by foreign loans, 70,000MW by the funds of construction firms, 299,300MW by Seoul city aid and 34,670MW by public bonds. This stands for that the amount of liabilities occupied 73.3 percent of the total funds.

3-6 Others

In the construction of subway line 3 and 4, concerted efforts have been exerted to reduce construction costs as much as possible, based on the knowledge and experience accumulated at the time of constructing subway line 1 and 2. The decision of the route was made with the first priority placed to preventing environmental disruption. All of the objectives have materia-lized, thanks to the devoted cooperation of seoulites.

4. Conclusion

At the inception of 1985, Seoul will be the seventh in the world in respect to prossessing long subway lines. Recent statistics has it that Seoul sustained 13.3 percent increase in traffic popula-tion during a year from June 1982 to June 1983, percent increase in public transportation facilities, 35.9 percent increase in cars, of which 50 percent are nonbusiness cars, and 0.3 percent increase in roads. The Government of Seoul city is to construct another four subway lines in the near future. The four lines under plan are line 5 of 12 Km, line 6 of 13 km, line 7 of 14.5 Km and line 8 of 19 Km. It is our ultimate goal to provide the passengers with the finest mass transportation conveniences so that they can commute safely, pleasently and rapidly.

Table 1 ; Construction Schedule of Seoul Subway Line

Division	Total	Line 1	Line 2 (Loop I		Line 3	Line 4
			Main	Branch		
Length in Kilometer	120.6	9.5	48.8	5.3	27	30
Station	102	9	43	3	23	24
Rolling Stoks	638	96	272		132	138
Headway in minute		3	3.5		3.5	3.5
Construction terms	71-84	71-74	78-83	78-83	80-84	80-84
passenger per day in million	5	1	1.5		1.2	1.3
Construction status		run	run	run	60%	60%
Construction costs in 100 million won	23,579	330	9,440		6,548	7,277

Note: 24.2MW is equal to US$ 30,250

Experimental test

In case of tunnel blasting, there is only one free-face-the tunnel heading. After the center holes are 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 extimated, as rocks very seldom show any sign of homogeneous quality. Experimental tests therefore have been implemented to calculate the specific charge of the explosves of certain strength, the spacing of holes and the diameter of holes to be drilled, as shown in the following figure.

As shown in the figure above, a series of holes are drilled at 800mm behind the free face to a depth of 1,200mm and firings are implemented at each holes with varied charge of explosives until the burden is teared off. Should it be realized, the specific charge of the rock to be blasted

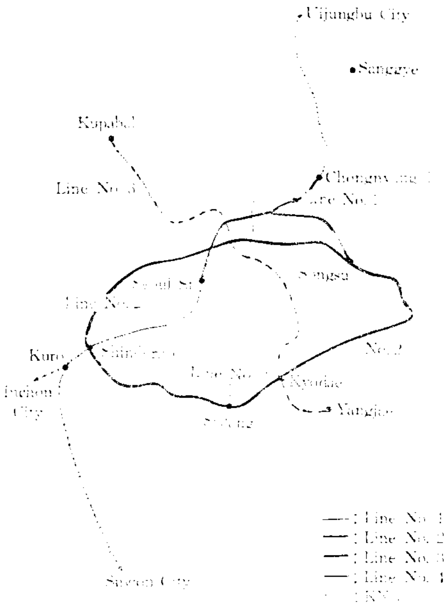


Fig 1 ; Seoul Subway Loutes

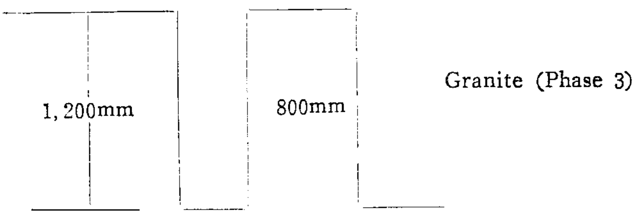


Fig 2 ; Experimental test of bench cut

can be calculated by the following formula:

$Ca=\frac{A}{SW}$ whereas A=ndi=m ; Activated area

S ; Peripheral length of charged room

Ca ; Rock coefficient

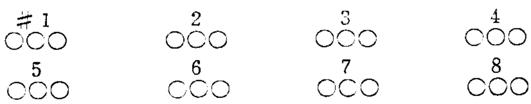
di ; Holes diameter

POWDER & NO. OF CAPS

	PHASE(I)	PHASE(II, II, I)	PHASE (IV)
BURDEN	60cm	65～70cm	75cm
HOLE SPACING	65cm	70～80cm	85cm
M/S CAPS	2pes	3 pes	4 pes
SLURRY	225g×2=450g	168×3=504g	168×4=672g
AN	112.5g×2×2=450g	112.5×3×2=675g	112.54×2=900g

*EX. SOFT ROCK III FIRING/ROUND (2 LANE SILULTANM WLY)

EDE



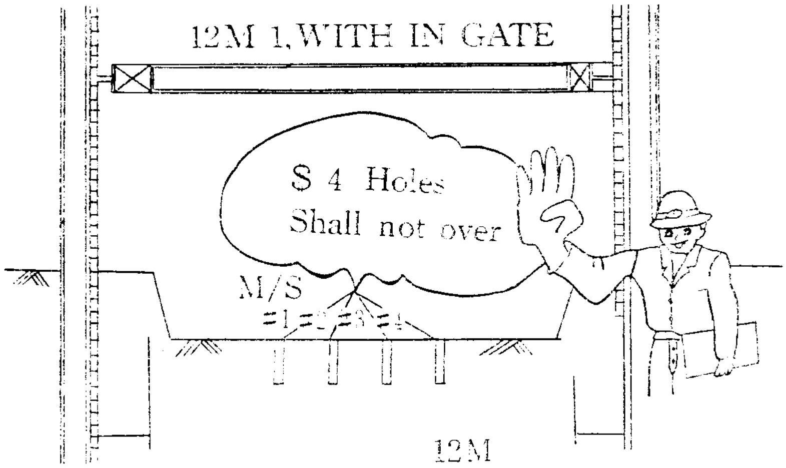


Fig 3 ; Open type and BOM blasting

Table 3 ; Standardization in tunnelling

	I	II	III	IV	V
Rock / Kind	Stable rock	moderately jointed and hard stratified or schistose rock	fractured and friable rock	untable plastic & squeezing rock	highly plastic squeezing & swelling ground
Burden (cm) Bit Gage=38mm	60	65	70	80	—
Drilling	full face	top heading & bench	top heading & bench	line-drilling (pilot drift & bench)	for pilling (〃)
Support	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

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

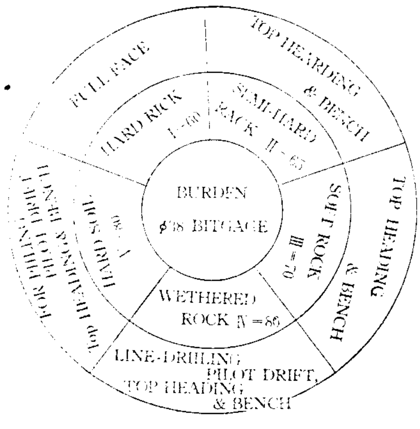
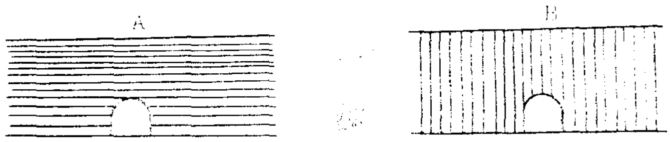


Diagram 1 ; Standardization of tunnelling

Table 4 ; Effects of the bedding state of geologival strata on blasting

A strike vertical to Tunnel axis				B Para strike Toward Tunnel axis		No. relation with strike
Dipping Direction		Reverse Dipping Direction				
Dip	Dip	Dip	Dip	Dip	Dip	Dip
45°～90°	20°～45°	45°～90°	20°～45°	45°～90°	20°～45°	0°～20°
Most Adaptalbe	Adaptable	Common	None-adaptable	very poor	Common	None-Adaptable



Empirical formula

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

For Gneiss : $V=KW^{0.5}D^{-1.5}$

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

W=Amount of Powder/delay kg

D=distance m.

V=Partical Vibration Velocity cm/sec

$K=\text{Coefficency}=E_i\ (R_i,\ Sc+Q_i)$

Sc : Compressire St. Kg/cm²

Ei : Powder Conpensation Ratio Dynamit=1

Slurry=0. 8

AN=0. 65

R : Rock Coefficency

Seoul Granite=0. 0371

Seoul Gneiss=0. 0206

Qi : Compensation by blasting pattern

		Granite	Gneiss
Open	Bottom Cut	80	60
	Bench	50	30
Tunnell	Center cut	60	40
	Bench	30	10

NO. 410 SITE
COMPRESSION ST. 1,450 kg/㎠ Bench)

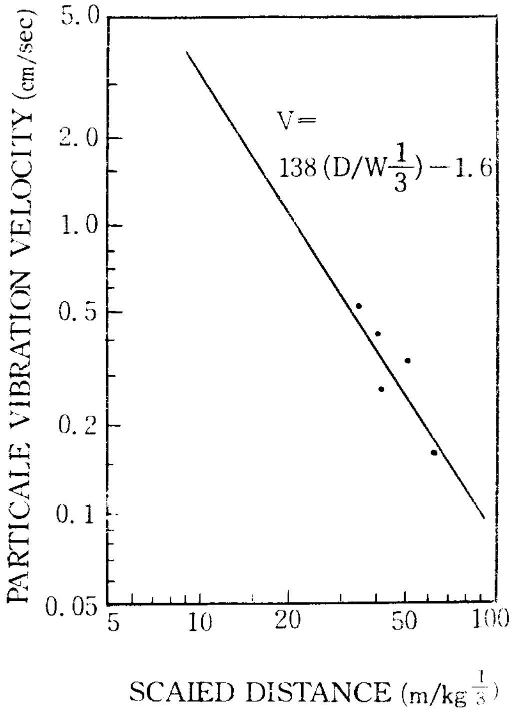


Diagram 2 ; Particla vibration Velocity

(No. 408 SITE,
COMPRESSION ST, 898 Hr/㎠)

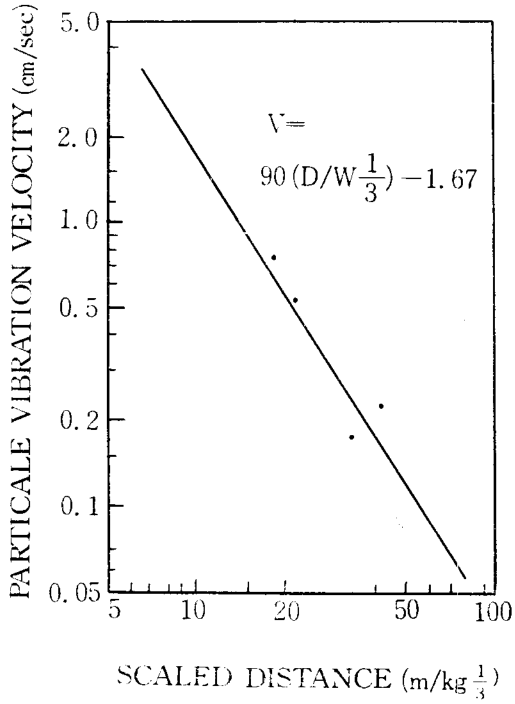


Diagram 3 ; Particle vibration velocity

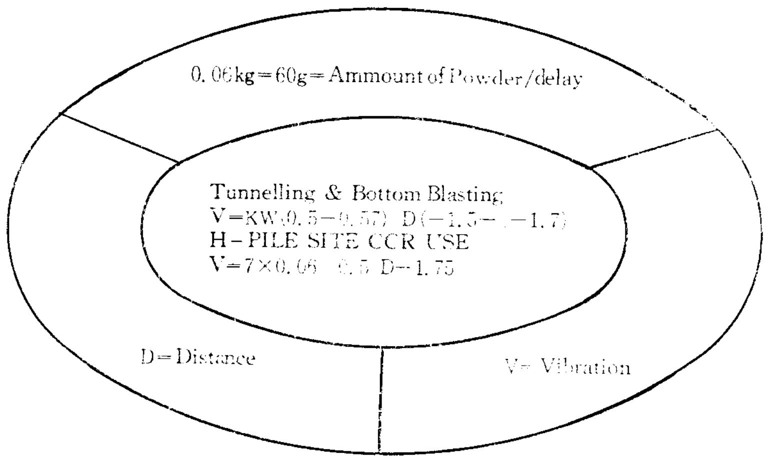


Diagram 4 ; Relation between vibration, powder & distance

Table 5 ; Vibration coefficient

S.M.S.C. Vibration Koefficency "K" Value (φ36mm Bit Gage)

		AN					SLURRY					DYNA-MITE	
Compression Strength kg/cm²		1,800—1,500	1,500—1,200	1,200—900	900—600	600	1,800—1,500	1,500—1,200	1,200—900	900—600	600	1,800—1,500	1,500—1,200
	Phase	I	II	III	IV	V	I	II	III	IV	V	I	II
Top heading	Cut	66	46—74	42—67	38—60	34—53	102	57—93	52—84	47—75	42—66	127	71—116
	Relief	63	26—55	22—48	18—41	14—34	78	33—69	28—60	23—51	18—42	97	41—86
Bench	Bench	76	39—68	35—61	31—54	27—46	94	49—85	44—76	39—67	34—58	—	—

Table 6 ; Vibration coefficient

K = COEFFICENCY (GRANITE)

		OPEN	TUNNELL	
	COMP.ST. (kg/cm²)	BENCH	CUT	RELIEF
DYNAMITE	1,800~1,500	117	127	97
	1,500~1,200	106	116	86
	1,200~ 900	95	105	75
	900~ 600	84	94	64
	600 이하	73	83	53
SLURRY	1,800~1,500	94	102	73
	1,500~1,200	85	93	69
	1,200~ 900	76	84	60
	900~ 600	67	75	51
	600 이하	58	66	42
AN	1,800~1,500	76	66	63
	1,500~1,200	63	74	55
	1,200~ 900	61	67	48
	900~ 600	54	60	41
	600 이하	46	53	34

Table 7 ; Vibration coefficient

5. K=COEFFICENCY(GNEISS)

	Comp.St.	OPEN BENCH	TUNNELL CUT	TUNNELL RELIEF
DYNAMITE	1,500~1,200	61	71	41
	1,200~ 900	55	65	35
	900~ 600	49	59	29
	600 이하	42	52	22
SLURR	1,500~1,200	49	57	33
	1,200~ 900	44	52	28
	900~ 600	39	47	23
	600 이하	34	42	18
AN	1,500~1,200	39	46	26
	1,200~ 900	35	42	22
	900~ 600	31	38	18
	600 이하	27	34	14

Table 8 ; Allowable value of blasting vibration

Rock type	Phase 1	2	3	4
Glassification	Cultural Treasure	Housing, Apt with Partial Crack	Shopping Center	Factory & Reinforced Concrete Bldg.
Vibration Value cm/sec (on Ground)	0.2	0.5	1.0	1.0~4.0

But 1. West-Germany Vornorm Din, 4150, Teil 3

2. Frequency up to 100Hz

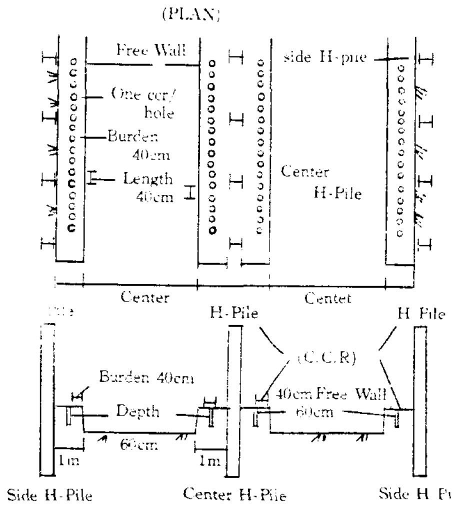


Fig 10 ; Blasting pattern near H-pile

NO. 321 DRILLING & BLASTING PATTERN (RO CK TYPE I)

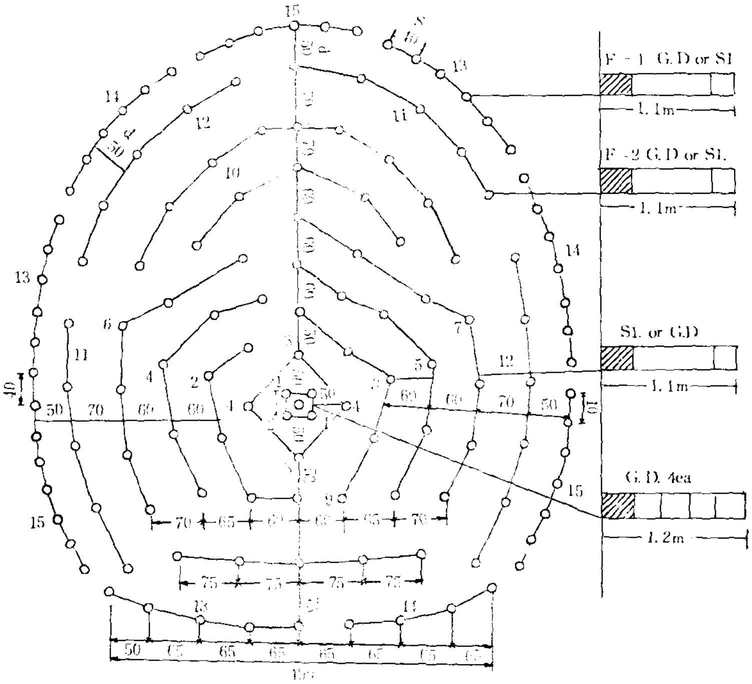


Fig 11 ; Drilling & blasting pattern (rock type 1)

NO, 321 DRILLING & BLASTING PATTERN(ROCK TYPE I)

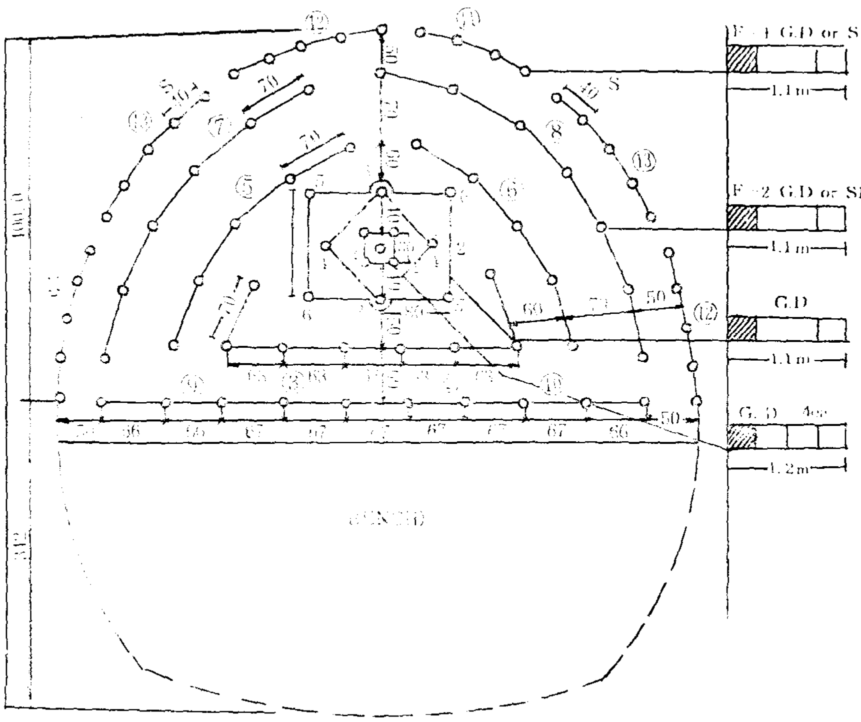


Fig 12 ; Drilling & blasting pattern (rock type 1)

NO. 321 DRILLING & BLASTING PATTERN

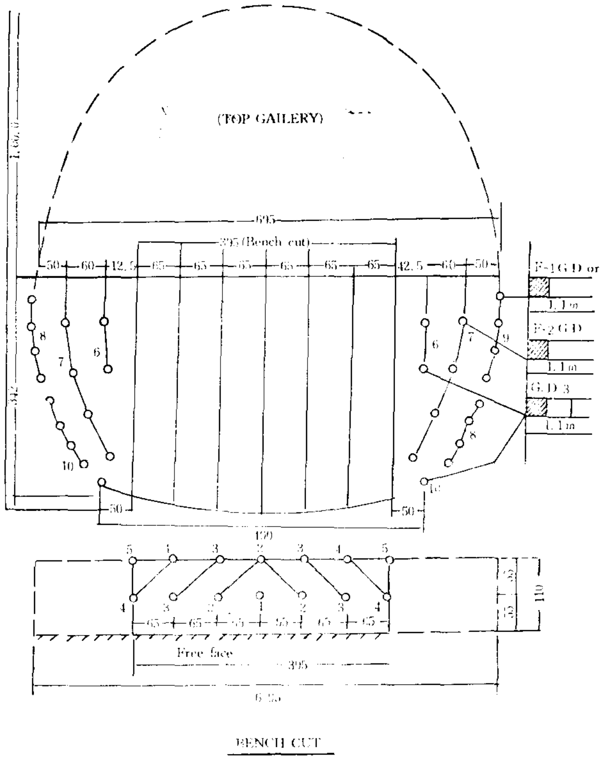
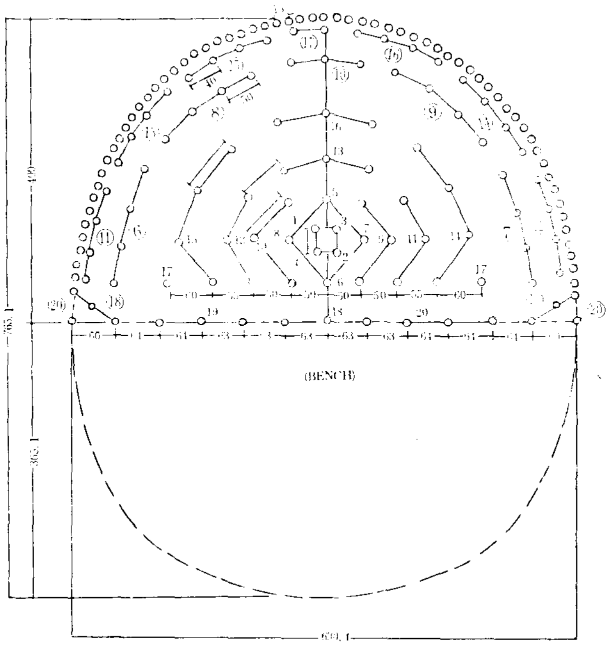


Fig 13 ; Drilling & blasting pattern (rock type 1)

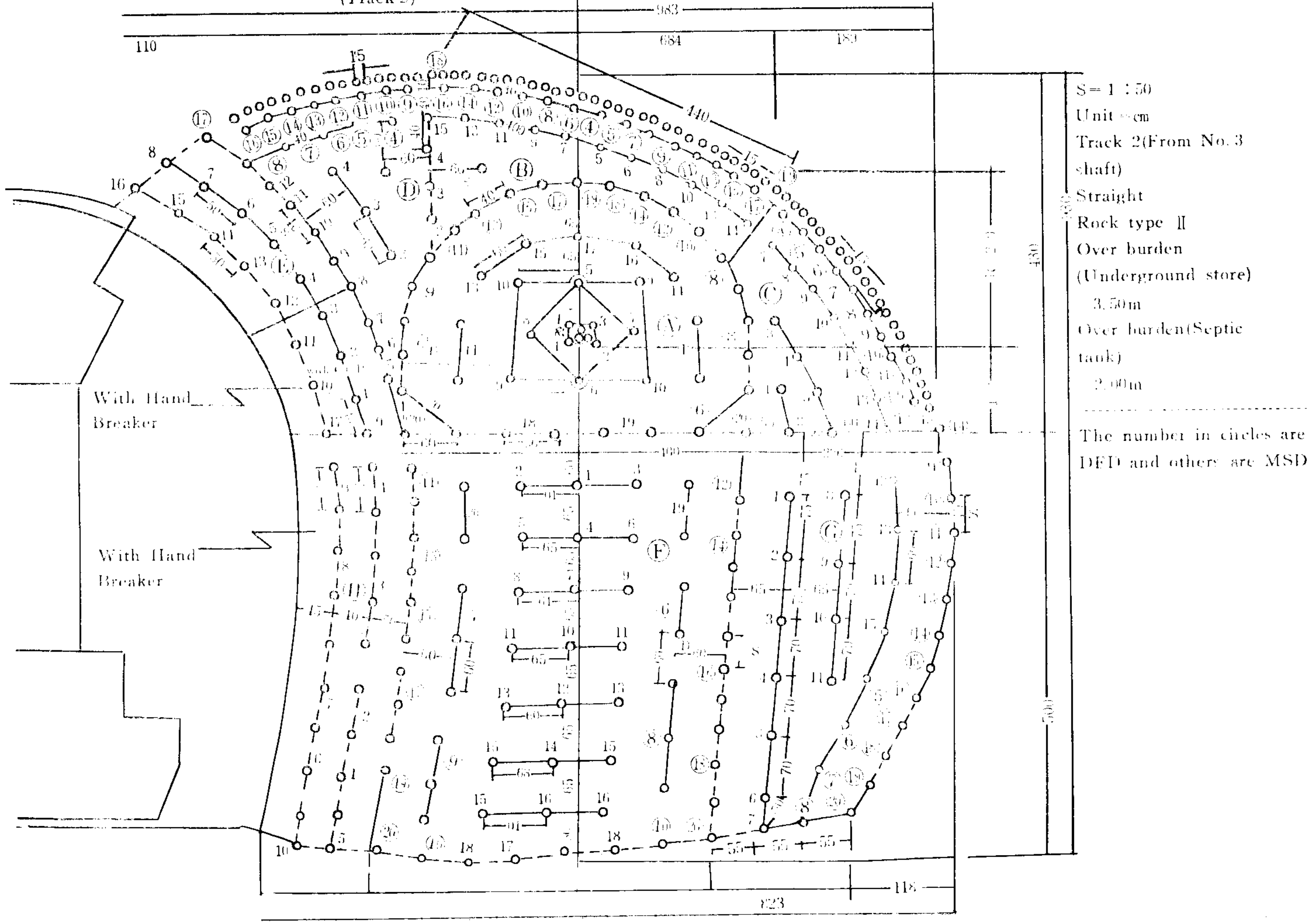
NO. 321 DRILLING & BLASTING PATTERN



S=1 : 50
R=700
Rock type Ⅲ
O : DEC
O OTHERS : MSD

Fig 15 ; Drilling & blasting pattern (rock type 111)

No. 415 UNDERGROUND STATION DRILLING & IGNITION PATTERN
(Track 2)



NO. 321 DRILLING & BLASTING PATTERN
(A TUNNEL, MYO DONG)

S=150
R=700
ROCK TYPE Ⅳ
ODED
Others MSD

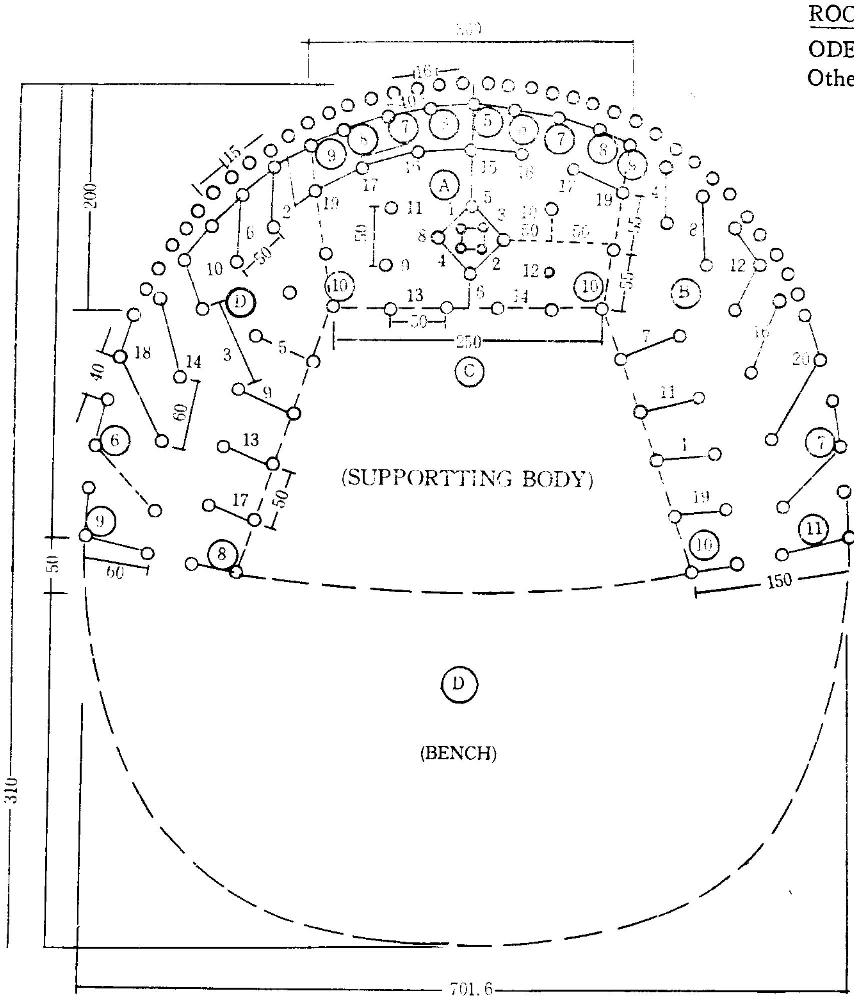


Fig 16 ; Drilling & blasting pattern (rock type Ⅳ)

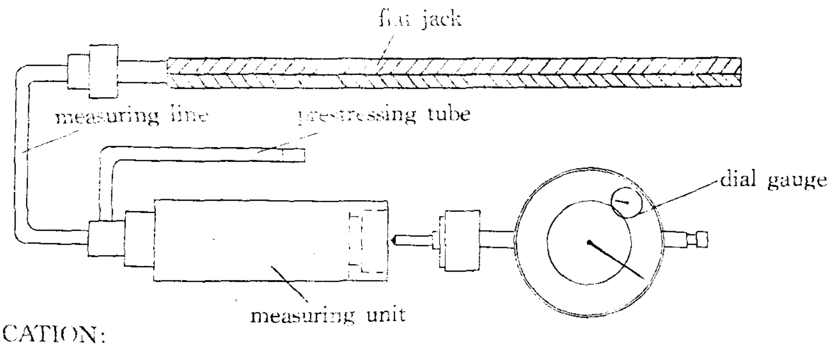
Equipments for measuring deformation and displacement

1. Load cell

Load cell is a kind of the hydraulic-mechanical stress tranducer which serves for measuring stresses in concrete linings or the stresses at interfaces between concrete and rocks in tunnels.

Load cell consists of a flat jack of steel filled with hydraulic fluid. The rigidity of load cell is adapted to that of concrete. For this reason, the load cell installed in the concrete doesn't represent an interference factor. A change in stress in the concrete is taken up by load cell in the course of hydraulic fluid's transmitting a pressure into the measuring unit by means of a tubing. In the measuring unit, the measuring fluid loads a spring package when implying hydraulic transmission converting the infinitesimal liquid displacement into a readable value. The standard measurements of the cell are 150 * 150mm. However, other sizes are deliverable, if requested.

For the manual reading or the remote indicating of the cell the same elements as interfels-extensometers can be applied. The -manual reading with a dial guage is made at the measuring unit, which is either directly mounted at the tranducer or is connected with the tranducer into the concrete (see drawing below). For measurement, the protective cap of the protective tube is srewed off. For registration, a mechanical logger and for remote transmission an electrical tranducer can be connected.



PLICATION:

Fig 11 ; Configuation of load cell

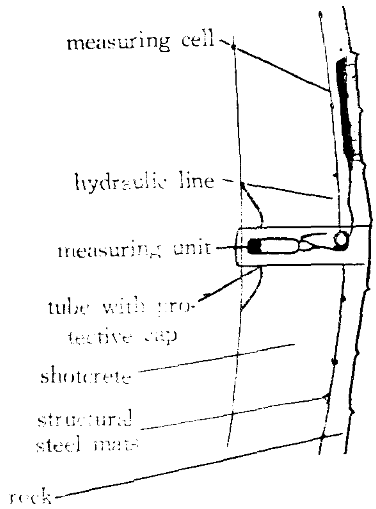


Fig 12 ; Installation of load cell

As there are no movable packing parts, the system practically works free of hysteresis. The identification line is linear all over the whole range. The accuracy of resolution amounts to 1/1000th part of the final value, namely, with tranducers having a measuring range of 0-50 bar it is 0.05 bar, with tranducers of 0-200 bar it is 0.2 bar. Temperature fluctuations of 5°C change the measuring value by 1%. In underground the temperature fluctuations are generally small, so that they can be neglected.

2. Convergency meter

Convergency meter is an apparatus designed to measure the displacements of the roof and side walls of tunnel, after shotcreting. Should the displacement measured exceed the estimated values as specified hereunder, additional rock bolting and shotcreting shall be implemented.

Table 11 Suggested data

Rock Class		Displacement
Phase 1	Hard	0~0.5cm
〃 2	Soft	0.5~1.5cm
〃 3	Weathered	1.5~3.0cm
〃 4	Sandy	3.0~5.0cm

Table 12 ; Frace evaluation standard

over burden	Arch crown's displacement, max	
	Hard Rock	Elasiticity Ground
10~50m	1~2cm	2~5cm
50~100m	2~6cm	10~20cm
500m up	6~12cm	20~40cm

3. Extensometer

This is a device to measure the variation state inside rock bed. As shown in the Figure 5 of the Attachment 4-2, a series of holes are drilled at roof and the walls of both sides, followed by the installation in the holes piano lines or steel rod, which function the indicators role of the settling state and displacement inside of the rock bed.

Table 13 ; Criteria for measurement

Classification	Necessity of Measurred
3D<h	X None
2D<h<3D	Good
D<h<2D	O Need
D>h	o Must Measured

4. Inclinometer

This is a device to measure the behavior of the ground and underground strata at the area where tunnel is constructed. As shown in the Figure 5 of the Attachment 4-2, a series of holes of different length are drilled from the surface downward, followed by the installation in the holes of measuring rods, by which the movement of underground strata is identified.

Fig. 13 ; Drilling & blasting pattern (rock type 1)

NO. 321 DRILLING & BLASTING PATTERN (ROCK TYPE I)

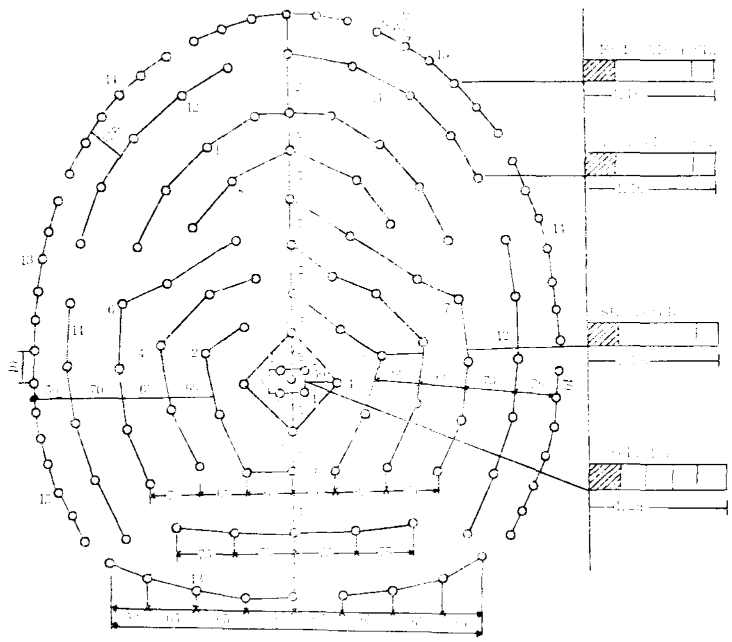


Fig. 14. ; Drilling & blasting pattern (rock type 1)

321 DRILLING & BLASTING PATTERN

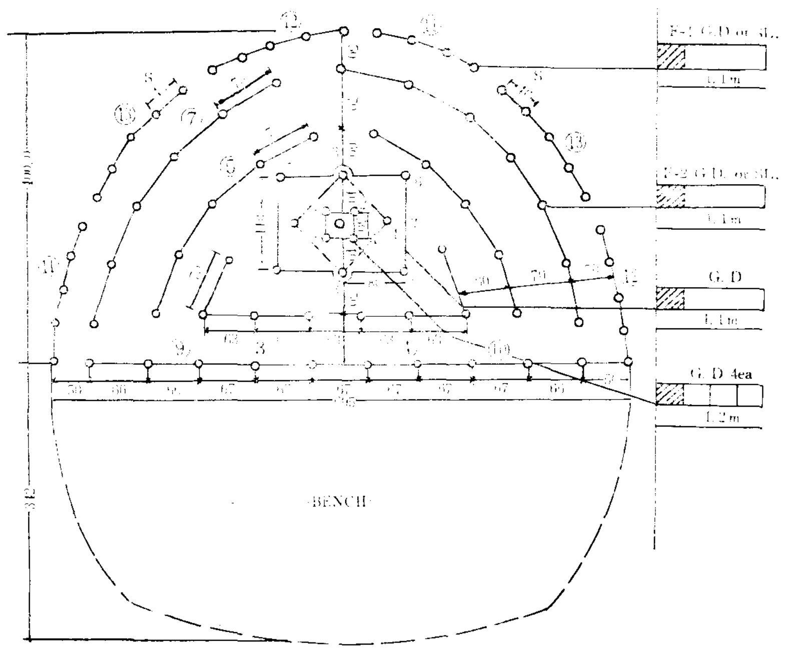


Fig. 15 ; Drilling & blasting pattern (rock type I)

NO. 321 DRILLING & BLASTING PATTERN

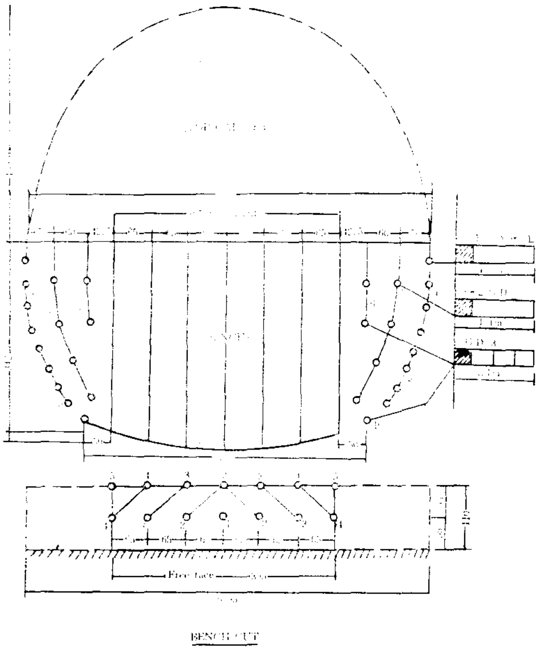


Fig. 16 ; Drilling & blasting pattern (rock type II)