Geological Survey and Exploratory Boring in the Construction of Seikan Tunnel

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1. Outline of Seikan Tunnel

1) Topography of Tsugaru Straits

Tsugaru Straits is situated between Honshu and Hokkaido in north Japan. Two portions in the Straits have the narrowest width of some 20 km between both lands. The east side, one of them, is through volcanic zone and the bottom is deeper than 200 m from the surface of the sea. Therefore, the portion of west side was decided the objecting area of the project.

Fig. 1. Topography of Tsugaru Straits.

For the first in the sea-area, precise topography (2m contour, 1/10000 scale) was made by means of echo- sounder (hydro-sonic) and observation of weather and tidal level and current in the local area were began, in 1947. They were need for geological survey thereafter. It was so hard to work survey in the sea- area that the tidal current had 2.0-6.5 kn. of speed at the middle portion and 1.5 kn. at the coastal side.

Fig. 2. Topography of the west Strait of Tsugaru.

2) Geology of the west Strait

Geological formation of the west strait consists mainly of Neo-Tertiary strata, and there are many moderate folds (synclines and anticlines) and large faults of some 10. Kunnui strata, named pyroclastic sedimentary rock in Miocene, have many dykes of andesite and basalt due to volcanic activity in Miocene. Yakumo strata, named shale in Pliocene, are much of cleavage due to folds. Kuromatsunai strata, named silt or tuff in Pliocene, are partially weak (2-4 MPa; q_u) and soft, in addition to un-congeal laminates of fine sand.

Followings were necessary to estimate ground- state or condition for the construction.

(1) Constitution of sedimentary strata and igneous rocks (intrusion).
(2) Structures of folds (strata).
(3) Faults (situation and magnitude).
(4) Dykes (situation and magnitude).
(5) Quaternary sediments, decomposed or un-congeal layers (situation and depth).

Fig. 3. Geological map of the part under sea of Seikan Tunnel (in rough).

2. Geological Survey before Construction

1) Geological survey in land- parts

Geological surveys in both land- parts were began before the part under sea in the area of object, in 1946. Methods of the survey in the land- part were general field-investigation, boring, seismic prospecting (propagation- velocity of elastic wave in the ground) and aero- investigation (geographical investigation from sky). The fruits were not only available for the construction in the land- part, but also very important to conjecture or verify with the geology of survey in the part under sea.

2) Geological survey in the part under sea

Methods of geological survey on the part under sea were seismic prospecting (since 1947), dredging (since 1953), investigation on the bottom of sea (since 1954), hydro-sonic prospecting (since 1959), boring (since 1962) and magnetic prospecting (since 1962).

Seismic prospecting was mainly to conjecture distribution of rocks and faults (fractured zones included). The seismic prospecting was so rough as hard in the middle portion, because that it was need to set shocker (blasting) and perceivers on sea-bottom.

Hydro- sonic prospecting was mainly to conjuncture structure of sedimentary layers and faults. The hydro- sonic prospecting was used widely in shallow and deep portion, because that hydro- phones and sparker were only towed by ship.

Dredging was directly to investigate distribution of rocks on the bottom. The dredging was used widely. However, it was less available for the hard bottom and under subsurface, because that specimens were gathered by means of dredger scratching only on surface of bottom.

Boring (to obtain core- specimens) was to directly to investigate distribution and state of rocks in vertical direction under sea- bottom. It could bored from 200 to 300 m of depth in shallow sea- bottom less than 50 m, that machinery was set on tower or turret off shore. Boring system of machine submerged to the bottom could be used in deep sea-area, but caught core length some 10 m under the bottom at a boring point.

The bottom of sea was investigated by direct observation and photograph with submarino in tow. The investigations were similar to field- and aero- investigation in land- parts. However, the investigations in the part under sea were not as clear as in land parts.

Table 1. Actual results of geological survey in the part under sea.

3. Tunnels for research

Geological survey on the sea was so finite of methods and conditions that the research in actual tunnelling was commenced, when considerable results of the geological survey in the part under sea had been obtained up to 1964. The purpose of the research was followings.

(1) To collate the geology of the tunnelling with the geology surveyed in the sea-area.

(2) To detail geological states or conditions of the ground in the portion under sea.

(3) To research methods and techniques of the construction in the state or condition.

The tunnels for research were instituted at both shores, with respect to the outline of the construction. One group of tunnels for research (at one side) consisted of an inclined shaft (-1/4 gradient) from the near shore to the portion under sea, 1st horizontal tunnel (3/1000 gradient) from the bottom of the inclined shaft at depth of some 300 m under sea- level and 2nd horizontal tunnel (-12/1000 gradient) branched off the medium of the inclined shaft at depth of some 150 m under sea- level.

The plan of the construction including scheme, designing and executing plans was concluded in accordance with geology and state of ground from the survey on the sea and the research in the tunnelling, up to 1971. However, the geological state was not sufficient of certainty, accuracy and precision to design in detail or to tunnel actually forward. Therefore, pilot and service tunnel had to be necessary in advancing to research geological state with the purpose above mentioned, in the plan. Then, pilot tunnel succeeded to the 1st horizontal tunnel and service tunnel to the 2nd horizontal tunnel.

The tunnel for research or the pilot (or service) tunnel had a roll to research methods and techniques on followings.

(1) Surveying geological state of the ground in a certain long front of face tunnelling.

(2) Available strengthening weak or broken zone in advance of tunnelling through that.

(3) Effective grouting into a certain regional front of face, to prevent water- inflow at face and after tunnelling through in ground borne water.

(4) Adequate tunneling (including system of excavation and support) in ground borne water or zone weak or broken, and in a certain long geological state including often those bad conditions.

The object of this report is geological survey. Hence, it may be mentioned after here on methods and techniques on “Surveying geological state of the ground in a certain long front of face tunneling”, those were mainly by means of horizontal borings.

Fig. 4. An example of the state tunnelling in the portion under sea.

4. Survey on geological state of the ground

1) Geological state of tunnelling under sea

If the ground before tunneling and the face and circumference after excavation had not been treated for prevention, various troubles concerning with stability of tunnel might occur in the ground loose or loosened, as followings in important order.

(1) Collapse in fore-upward portion about the face, often with much water-inflow.

(2) Failure in the face (involving un- self-standing), often with water-inflow.

(3) Stable state in the face (involving self-standing) within a certain time. However, phenomena scaling or slaking in soft ground or dropping or slipping down off seam in cracky ground might occur in the circumference.

ⅰ : in the circumference next to the face.

ⅱ : in the circumference near the face.

ⅲ : in the circumference a little far from the face.

Fig. 5. Phenomena of collapse or failure in vicinity of the face tunneling.

Much water-inflow with high pressure might be only itself important trouble in tunneling and operation after completion, but also concerned with collapse or failure of above mentioned. Besides, there might be troubles of large deformation or displacement in circumference, for example swelling or squeezing phenomena.

Mainly following characters in the rocks might cause those phenomena.

(1) Physical properties (strength, rigidity, toughness, ---).

(2) Mineral compositions (alteration, decomposition, weathering, ---).

(3) Frequency or density of cracks in rock- mass (joints, cleavages, schistose,---).

(4) Degree of fracture due to faults or dykes (breccia, sand, gouge, ---).

(5) Hydro- mechanical properties in rock- mass (storability, permeability, ---).

Of course, pressure of earth and ground- water might act with them.

The most reliable method to investigate those characters was the boring to get core-specimens (core- boring), at the time from 1960s to 70s. It was necessary of observation and examination on the core gotten and the hole bored to catch characters above.

Table 2. Observation and examination on the core- specimens and the hole.

2) Survey in advancing front of the face tunnelling

It was always to survey geological state in advancing front of the face tunneling research (pilot- and service- tunnel). The method was the core- boring horizontally in direction tunneling (exploratory boring), from the adit or alcove (boring- base) by the side of the tunnel. The disposition of geological state in the ground was conjectured by one boring in monotonous condition, but by plural borings in complicated condition.

Fig. 6. An example of arrangement of exploratory boring in tunnelling.

5. Contrivance of exploratory boring

1) Obstacles in horizontal boring

It is better in the tunnelling as that exploratory boring -speed and -length are more. However, it's not so easy as that horizontal boring has more obstacles than vertical. To use conventional boring- system into horizontal direction yields following problems.

(1) Vertical gravity acts bit and rod to contact circumference of the bore- hole. Therefore, friction acts bit and rod in the direction of both rotation and thrust. Rotary and thrust- forces that are equal to friction and necessary force for bit to cut ahead at bottom of the hole must be transmitted the rod from the machine.

(2) The forces transmitted from machine and frictions deform the rod bending and the bit orienting. Therefore, to control the direction boring is very difficult. The force or frictions are larger with the hole longer. Therefore, the machine is necessary of more power and the rod is necessary of more rigidity and strength.

(3) The circumference of the hole falls down easily in fragile rock. The fragments falling down and cuttings bored have the tend to stay down side of the hole. They increase not only the friction but also the bent of the hole, sometimes bit or rod is detained (involving jamming). (1), (2) and (3) increase reciprocally.

Besides, water- inflow with much quantity or high pressure obstructs boring- works.

Fig. 7. Obstacles in horizontal boring.

2) Improvement of boring- system

The conventional system with wire- line to catch core was adopted at the beginning the exploratory boring- system with tunneling for research. The improvement to solve problem was pursued one by one, for example correcting vent of the hole by means of cutter- head driving with collar. But, it succeeded that one problem became small and another grew. After research for ten years, the comprehensive exploratory boring- system was concluded as followings.

(1) To bore with less vent and large length (about thousand meter).

(2) To measure situation of bore- hole by inclinometer for bore- hole.

(3) To add borings from the near portion that has problem of geological state, that is conjectured by the exploratory boring heading.

To execute them above in effect and efficiency needed synthetically following means.

(1) To circulate reversibly the boring- water in general method.

(2) To set various kinds of stabilizers on the rod to keep the direction boring.

(3) To bore with double tube through the bore- hole intent to collapse.

(4) To bore by powerful machine appropriated to the horizontal exploratory boring.

Fig. 8. Boring- systems for exploratory in horizontal direction.

6. Facts of exploratory boring in Seikan Tunnel

The system of reverse water-circulation made boring- speed higher, in addition to reduced troubles of the direction venting, the circumference collapsing and the cuttings remaining. A provision was the defect that the core of ground fractured, altered or decomposed was gotten as roughen, broken or resolved by circulation- water. When the specimen was necessary un- damaged, the core- barrel was inserted inner tube only at the time. Inclinometer or other probe was used like as core- barrel.

A combination of bits and stabilizers set at certain positions on the rod had a tendency to advance toward a situation. The tendency depended on structure and lithology of strata or layer. It could be able by utilizing the tendency to long boring that the locus was set within a little off straight line planned.

Fig. 9. An example of combination of bits and stabilizers.

Fig. 10. An example of locus of hole bored (reverse circulation with single tube).

In the time introduced conventional method with wire- line, the average speed of boring was 1.6 m/(8h) in ground fractured and 4.1 m/(8h) in ground partially fractured, in addition that the length boring was from 200 m to 600 m. After the time introduced method improved, the average speed of boring was 5.1 m/(8h) in ground fractured and 9.4 m/(8h) in ground partially fractured, in addition that the length boring was from 500m to 1200m. Moreover, the length boring in one hole could be reached nearly 1500 m and 2150 m of maximum record.

Fig. 11. The longest borings before pilot tunnel pierced in the middle portion.

In the case that geology fractured, altered or decomposed was less sufficiently forecasted in surveying and researching term or detected by boring advancing in tunnelling, the structure and state was investigated in detail by borings added to advancing boring. It was general to add borings of length from 200 to 700 m at near the ground with the problem. In the case that the structure and state were known as more complex and important, it was necessary to add more borings of length from 100 to 200 m at the face tunnelling, step by step through the ground with the problem.

Fig. 12. An example of boring added to survey in detail on the state with problem.

It was much of efficiency and effect in tunnelling that exploratory horizontal boring in long or short range was adopted machine appreciated to each condition. Those boring- machines were invented or developed compact, light and powerful for easy operation at the set- position in adit, alcoove or face tunnelling and to the ground-condition.

Fig. 13. Example of machine appropriated to long horizontal exploratory boring.

Table 3. Example of machine appropriated to horizontal exploratory boring.

7. Conclusion

Geological survey for the construction of Seikan Tunnel is summarily concluded as followings.

(1) The geological survey on the sea- area (included land- part and research tunnelling) before the construction, that was as well as possible with technology at that time, showed whole profile and gave peculiar knowledge in the area. That was very important and available for the survey in the construction.

(2) The geological results on the sea- area were not sufficient in certainty, accuracy or precision for the construction. And actual tunnelling needed not only geology but also the state of ground. It was necessary that the tunnel (pilot or service) advanced with researching the geology and the state to construct main tunnel.

(3) Pilot or service tunnel advancing needed to forecast geology and state of ground in detail. Exploratory boring to get specimen was the most reliable of the forecast. In the case of the complex geology in bad ground or with much water, it was efficient that short exploratory borings were added from near the portion with problems.

(4) The exploratory boring had some subject, that was to bore long range and in bad condition (fractured, altered, decomposed or un- congealed), with high speed. It was possible with the boring- system of reverse water- circulation, stabilization in direction and double tube.

(5) The system of the exploratory boring was practiced by use of the boring- machine appreciated to horizontal direction in tunnel. It was adequate to the aim that the boring machine was developed or invented synthetically in equipment, power, weight, figure, arrange of parts and so on.

(6) It has indicated a general method and procedure of the geological survey for the construction of tunnel under deep sea, in the case that the ground has complex geologies, bad conditions and other important problems like as heavy water pressure.

Acknowledgement

This report refers much to “ The Record of Geological Survey in Seikan Tunnel” (in Japanese, not published). The record was compiled by Seikan Construction Bureau of Japan Railway Construction Public Corporation in 1989 after commencement of operation of Seikan Tunnel (1988).

The compile depended much on Mr. Kenichi MAEDA (Bachelor of Science, Geologist), engaged in practice to survey the geology from 1962 to the accomplishment (1985) and to rearrange the fruits after the accomplishment to 1993 for Seikan Tunnel. Hence, I would like to express gratitude for his great contribution.

Appendix

A Proposal of the System using Exploratory Boring for Tunnelling by TBM in Deep Ground with High Water- pressure.

1. Troubles in tunnelling by TBM at deep ground with high water- pressure

If the ground before tunnelling and the face and circumference after excavation are not treated for prevention, the phenomena may occur as mentioned in 4. 1). The phenomena may occur on TBM tunnelling in deep ground with high water- pressure, various troubles as followings.

(0-1) Water to inflow with high energy near the face.

(0-2) Ground near the face to fracture with collapse, often with much water inflowing.

(0-3) TBM advancing with excavation at the face not self- standing to loose ground and to introduce possibly the phenomenon (0-2).

However these phenomena may make tunnelling very hard or impossible to advance with any system, it may be so more trouble in cope with those situations as that TBM hinder at near the face, than TDB (the system tunnelling by drilling and blasting) or TPM (the method tunnelling by machine partially excavating, for example Load-Header, Alpine- Miner etc.).

Following troubles are concerned with using disk- cutter to chip rock.

(1-1) Disk- bit to chip less due to rock hard (uni- axial strength more than 80 MPa) or much of abrasive component (quartz more than 40 %).

(1-2) Disk- bit to bite less due to rock soft (elastic modulus less than 3 GPa) or much of un- consolidated constitution (clay and sand more than 40 %).

Following troubles may occur in the case tunnelling by TBM without shield.

(2-1) Rocks in circumference to fracture with slaking or slipping down between cutter- head and rear shoe.

(2-2) Gripper not to be propped due to circumference weak or soft.

Those problems yield choice of support- or reinforce- system and alternation of setting time and position on circumference.

Following troubles may occur in the case tunnelling by TBM with shield.

(3-1) The shield not to advance due to hard breccia detained in sliding joint (between front- and rear shield).

(3-2) The shield not to advance due to large deformation of circumference slaking, swelling or squeezing.

(3-3) Rocks in circumference slaking or slipping down in variety after shield (problem of choice or alternation of supporting system or segment).

Fig. A1. Longitudinal Profile of TBM System arranged.

2. Planning exploratory boring for forecasting geological state

1) Exploratory boring

Trouble above mentioned may yield in various geology and state of the ground that are mentioned in section 4. 1). It may be important and main role to forecast the geological state with the observation and examinations in Table 2. by boring. Here, the exploratory boring is proposed as basic method to forecast geological state.

There have been devised or invented boring apparatus with equipments controlling, inspecting or testing in boring instead of observation and examination in Table 2. However, they may be inferior to the simple boring system in boring speed and length, and have higher risk detained by jamming in horizontal boring, nowadays. Therefore, the boring system improved in Seikan Tunnel may be better in application.

The range of length is fit to the object in the forecast. The length to fit to the object early to plan long section may be more than 500 m, average some 1000 m (long range). The length to fit the object to assure geological state may be more than 300m, average some 600 m (medium range). It is advisable rule that these borings are arranged on both side of tunnelling.

In the case of that the boring needs higher speed or the core- specimens are not useless, the boring method not to get core (so called; non - core boring) may be sufficient for the object by means of geophysical inspection or logging, as mentioned below.

In the case of the boring to survey the geological state heavily fractured, altered or complicated in detail, the fit length of range may be from 100 to 300 m with all coring (short range).

Fig. A2. An example of exploratory borings arranged both side of tunnelling.

2) Alcove for exploratory boring

In the case that the tunnel has no room for the space near the face, alcove or adit for exploratory boring may be set with widening the tunnel. In the case of the type of machine appropriated in horizontal direction, alcove more profitable than adit in cost and time of setting. The width of alcove may be from 2.5 to 3.0 m, and the length may be about 25 m for long range and 15 m for medium range. It may be set alcove by following procedure; excavating with TBM a certain gap venting and straight within necessary at first, backing TBM at starting point and excavating along the line tunnel route.

Alcove after the boring finished may be used for the substation of electric power, the facility of drainage, the facility of ventilation, the storage of materials and tools, and so on in tunnelling.

Fig. A3. Example of arrangement in alcove for exploratory boring.

Fig. A4. Example of alcove and adit set by TBM.

3. Geo- physical prospecting

1) Inspection and logging in bore- hole

There are various characters of geo- physics usable for prospecting. They are speed migrating elastic wave, density, specific electric resistance and so on. The geology and the state of the ground may be prospected synthetically by various kind of those data or collation to ground directly inspected.

Core- specimens gotten by boring may not always indicate accurately the state of the ground, because those core- specimens may be broken, desolated or lost in catching and conveying in bore- hole. Non- core boring may be alternated for some reason so as speed or length boring. In those cases, it may be adopted to prospect the state of the ground that the geo- physical method continuously inspects the bore- hole in a section. It is called "logging". Instead of inspecting directly the ground, visual inspection on circumference of bore- hole by probe of camera or televiewer may be general.

The logging needs the probe made specifically for bore- hole. Besides, It is necessary special apparatus and equipment to insert, convey and set the probe in the long bore-hole in horizontal direction.

Fig. A5. Example of system logging in bore- hole.

2) Geo- tomography

If the geological state is required in spatial arrangement, it is necessary the sufficient knowledge from experiences and studies about the ground or some exploratory borings added to survey in detail. The geo- tomographical method using exploratory bore- holes may be efficient and effective to forecast the geological state in spatial front of the face, instead of some borings added to general exploratory borings.

Any geo- physical character to permeate through ground may be used for the geo-tomography. However, seismic (speed migrating elastic wave) and electric (specific resistance) tomography is the most usual, nowadays. It is important to collate with logging in bore- holes or examination on core- specimens. Recently, radar- (speed migrating radar) tomography is studied to application the geo- physical prospecting.

Geo- tomographical measure in long horizontal bore- holes arranged wide space may need efficiency mainly to improve followings.

(1) Special apparatus and equipment to insert, convey and set the probe in the long bore- hole in horizontal direction.

(2) Number or length of probe (emitters and receptors) on one measurement.

(3) Strong emitter or sensitive receptor.

(4) Probe bearing much water in flowing with high pressure.

Fig. A6. Examples of geo- tomography used bore- holes.

Tables in "Geological Survey and Exploratory Boring in Construction of Seikan Tunnel"

Table 1. Actual results of geological survey on the part under sea.

Year	Survey executed		
1945	Rough investigation on the vicinity of Tsugaru Straits.		
46	S; 1 km (T).		
47	S; 19 km(T-Y).		
48	S; 1 km(T), 1 km(Y).		
53	S; 17 km(C-Y),	D; 12 points(C-Y).	
54	S; 7 km(across C-Y),	D; 36 points(T-Y),	Ip/Io; test.
55	S; 7 km(across C-T),	D;1932 points(T-Y),	Ip; 1500 photos(T,Y).
58	D; improved 31 points(T-Y),	Bs; 9 m/19 points(T,Y).	
59	H; 208 km /26 lines(T-Y).		
60	Io; 17 km/17 lines (T-Y) .		
61	H; 309 km /42 lines (T-Y).		
62	D; 68 points(C,Y),	Bt; 200 m(Y1),	M; 352 km/45 lines(T-Y)on ship.
63	Bt; 200 m(Y2),		
64	S; 2 km/2 lines(Y)		
65	S; 4km/4 lines(Y),	Bt; 250 m(Y3),	
66	Bt; 230 m(T1),		
68	Bs; 4 m/11 points(C,T),	H; 262 km /38 lines(T).	
69	D; 69 points(C),	H+M; 341 km /61 lines(T).	
70	H; 907 km /80 lines(C-Y).		
72	M; geomagnetic map of the area (1/20000 scale) on airplane.		
1978	Bs; 100 m/44 points(C).		

Note 1) Methods of survey are indicated with following symbol letters.

S: seismic prospecting, D: dredging, Ip: photographing the bottom of sea,

Io: investigating the bottom of sea with submarino,

H: hydro-sonic prospecting, Bt: boring (tower off shore),

Bs: boring (submerge), M: magnetic prospecting.

2) Surveyed portions are indicated with (symbol letters) followings.

T: off shore of Tappi (Honshu side), Y: off shore of Yoshioka (Hokkaido side),

C: central portion of the strait, T-Y: between T and Y etc.

3) Executed quantities are indicated followings, respectively method of survey.

S, H, M, Io; total length of surveyed line/number of surveyed lines.

D; number of points gathering specimens.

Bt, Bs; total length of obtained cores (bored holes)/number of boring points.

Table 2. Observation and examination on the boring- specimens and the bore- hole.

Observation and Examination	: Objective Characters
Specimen	
Observation of aspect of core	lithology, fracture, alteration or decomposition
Physical test of core	strength, speed of sonic wave, rigidity
Mineral analysis of core	lithology, alteration or decomposition
Measurement of core	density, cracks, swelling, failure with water
Ionic analysis of inflow-water	existent state and origin of ground-water
Analysis of gas resolved in water	existence of fuel or harmful gas
Boring hole	
Measurement of temperature of inflow-water	: temperature of ground
	: existent state and origin of ground-water
Measurement of inflow quantity and pressure	: storability and permeability
Measurement of inclination and direction of bore- hole	

Table 3. Example of machine appropriated to horizontal exploratory boring.

Name (production)		Fs-30S (KOKEN)	TOP-L (TONE)	Fs-60C (KOKEN)	TOP-LS (TONE)
Size	(mm)				
	height	950	800	1,460	900
	length	1,350	3,370	4,400	4,000
	width	600	930	780	800
Weight	(kg･f)	800	1,500	3,000	2,900
Spindle	(mm)				
	stroke	500	1,800	1,700	1,800
	inner diameter	108	170	120	170
Output					
torque	(KN･m)		14.0		
	low revolution	4.0		11.4	14.0
	high revolution	1.1		3.1	3.5
thrust	(KN)		50		100
	forward	50		160	
	backward	62		230	
Uses					
boring- length(m)		100~300	200~700	500~1,200	500~1,200
geological state		heavily fractured----partially fractured------------			

Note: TOP-LS has the faculty of reverse circulation with double tube in itself.

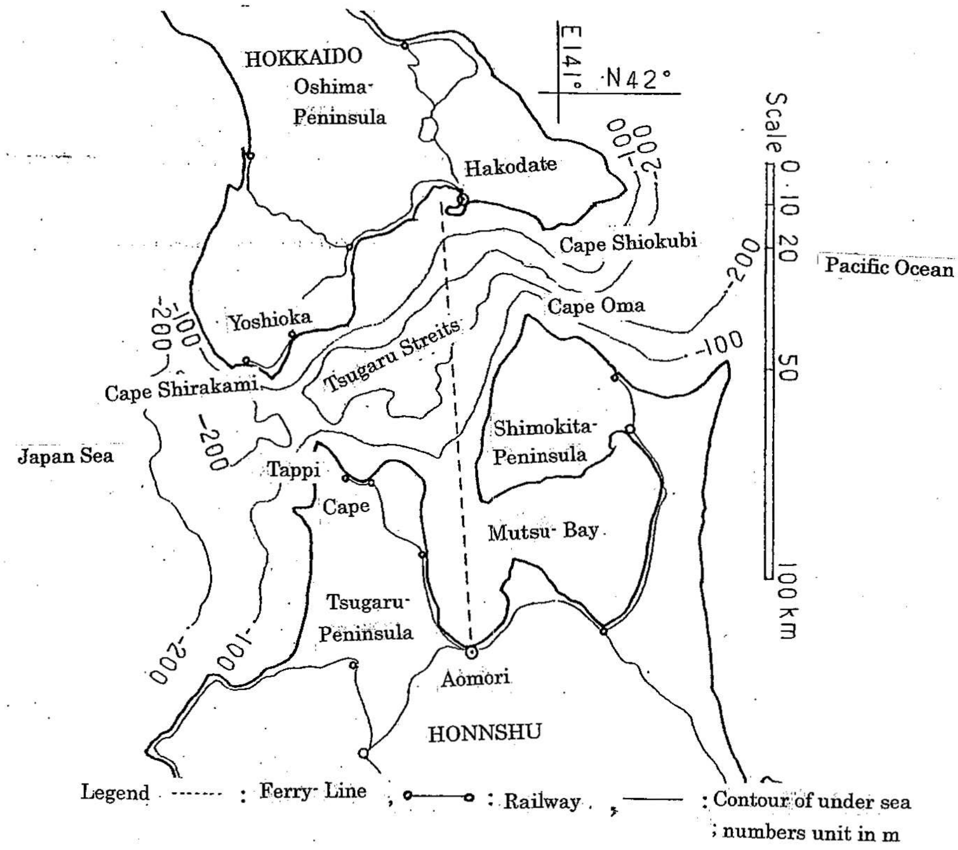
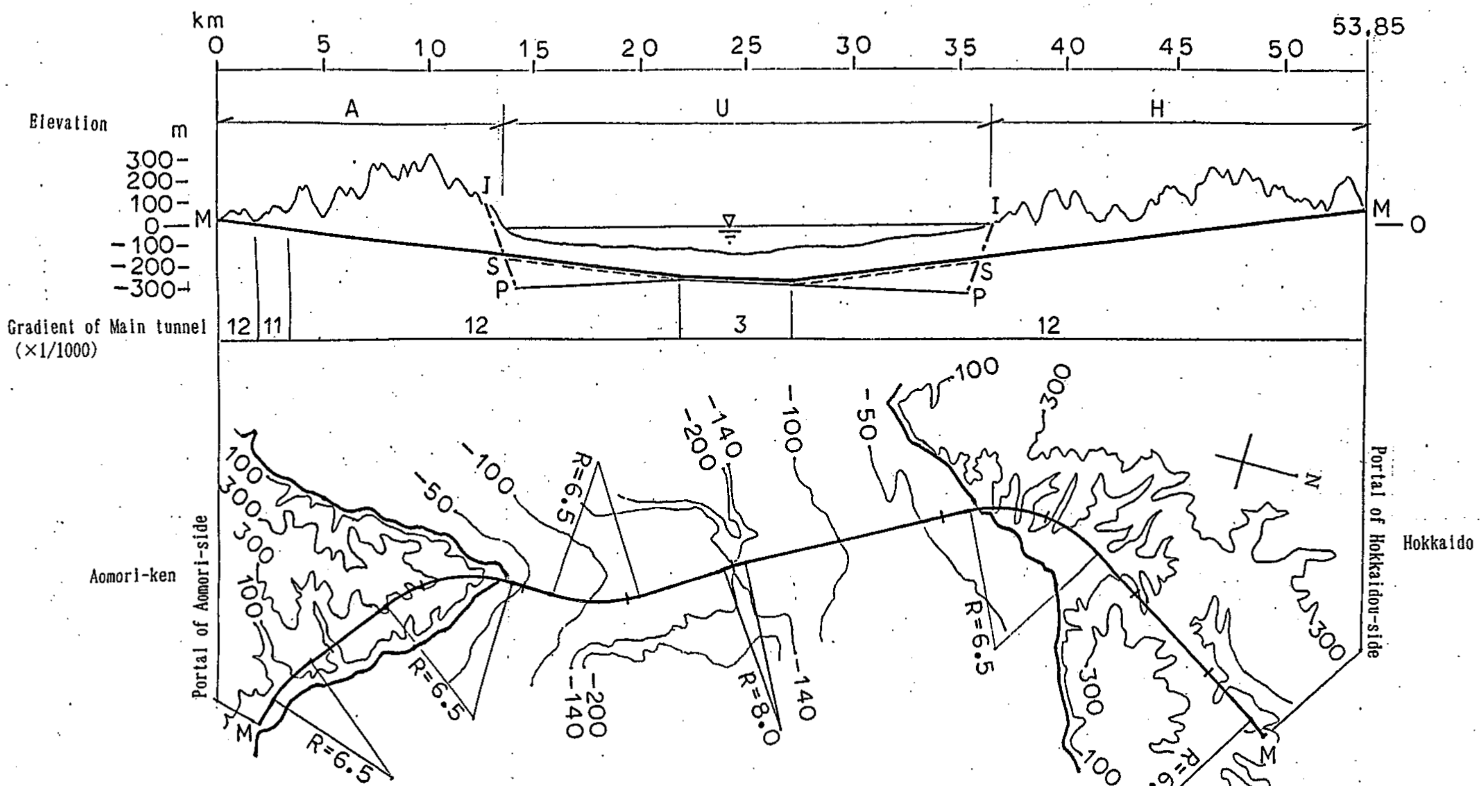


Fig. 1. Topography of Tsugaru Straits.



Longitudinal profile of Seikan Tunnel in drawing .

Legend M:Main Tunnel ,P:Pilot Tunnel, S:service Tunnel, I:Inclined Shaft,

A:Land part of Aomori-Ken,U:Part under sea ,H:Land part of Hokkaido

Note:Contour unit in meter, Radius unit in kilo-meter.

Fig. 2. Topography of the west Strait of Tsugaru

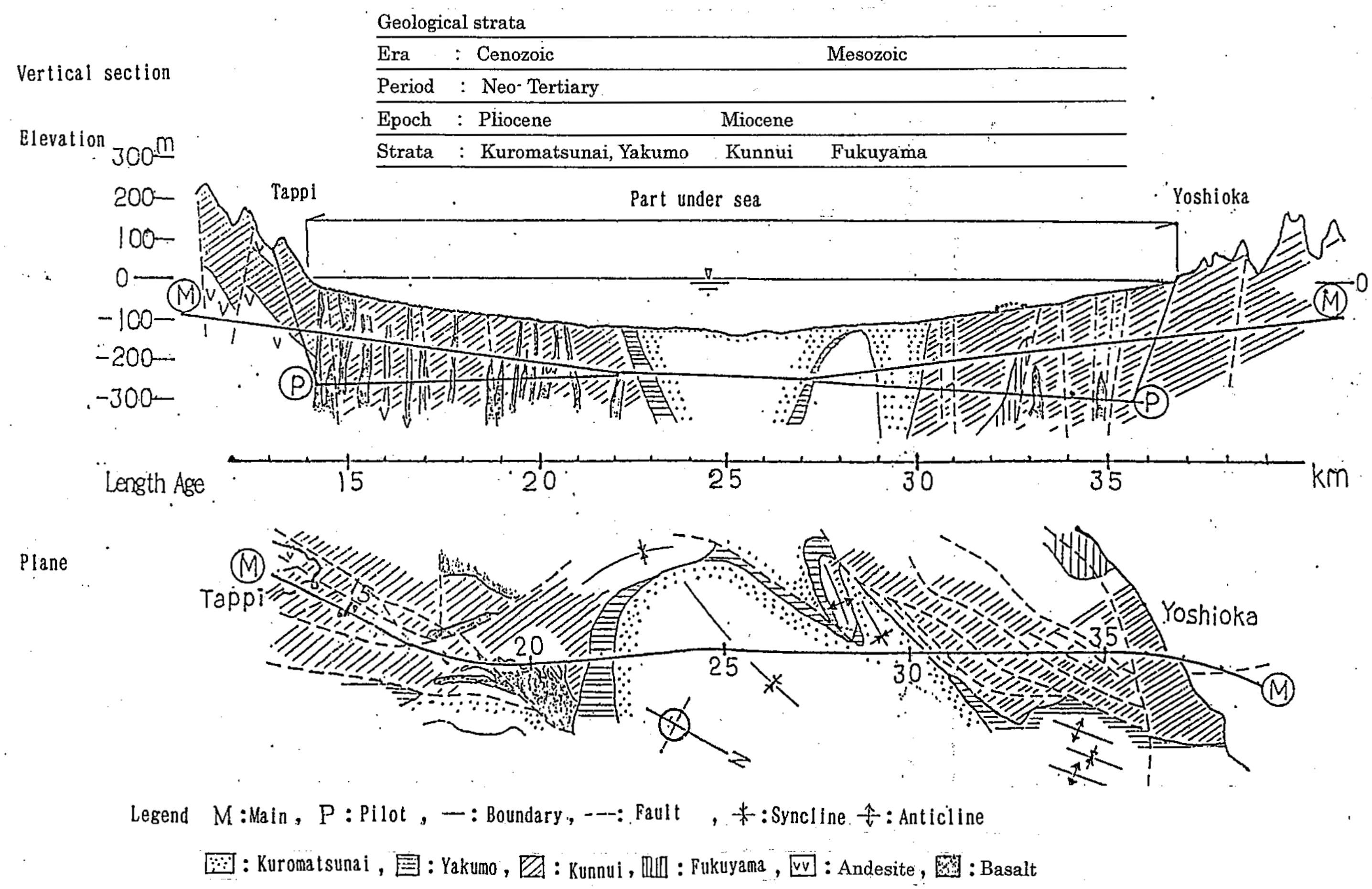
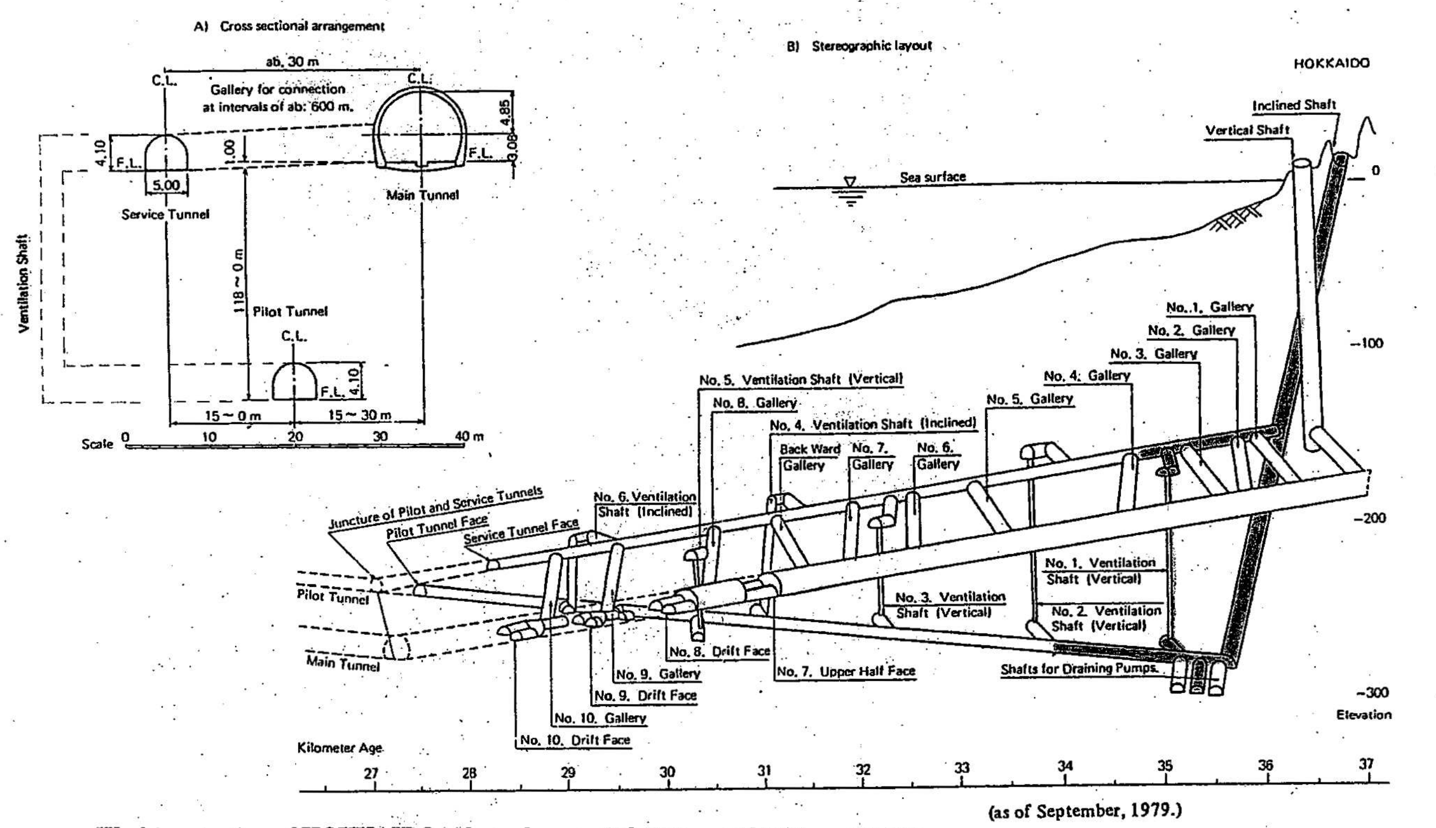


Fig. 3. Geological map of the part under sea of Seikan Tunnel (in rough).



Working section of HOKKAIDO side under-sea:38k600m—23k900m=14k700m

: Section tunneled in researching time.

Access-shafts	Cross-sectional Shape	
Inclined(Gradient:1/4)	basket handle(H:4m,B:5m)	length:1210m
Vertical	circular(ϕ:6.5m)	depth : 182m

Fig. 4. An example of the state tunnelling in the portion under sea.

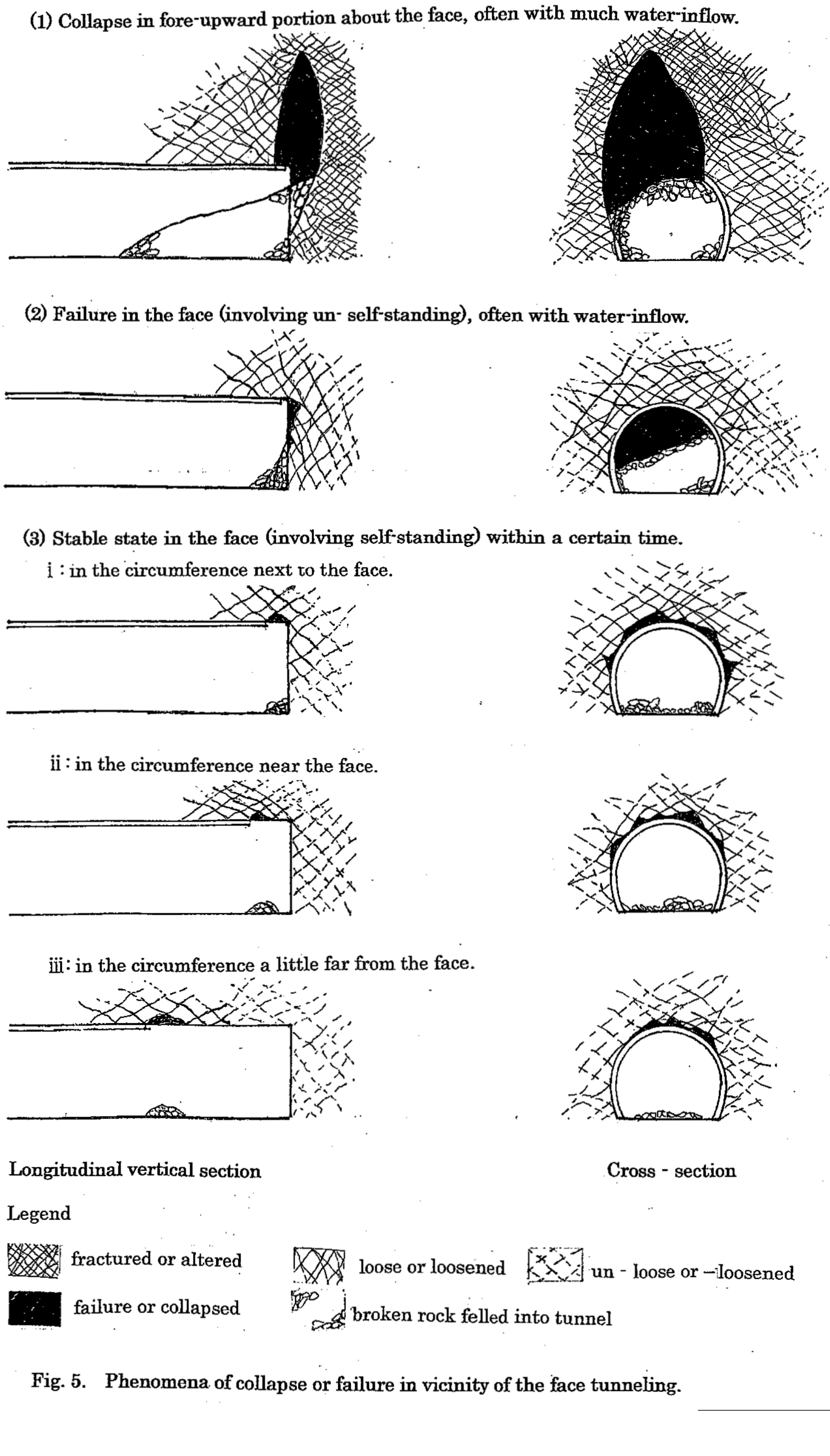
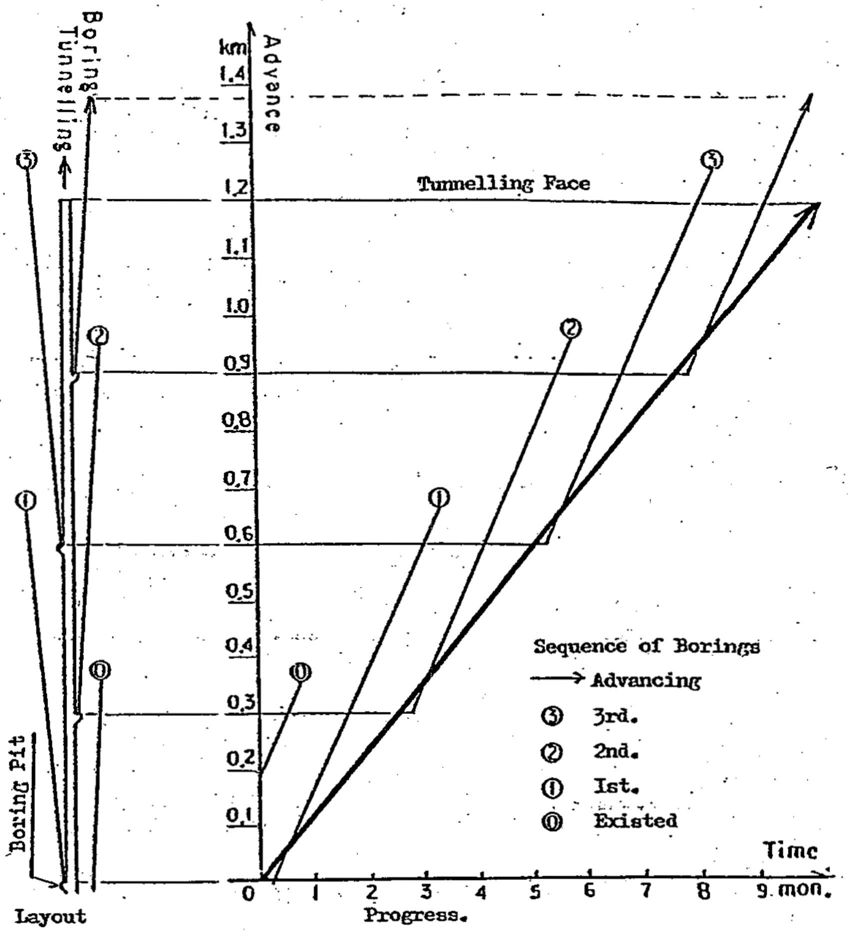


Fig. 5. Phenomena of collapse or failure in vicinity of the face tunneling.

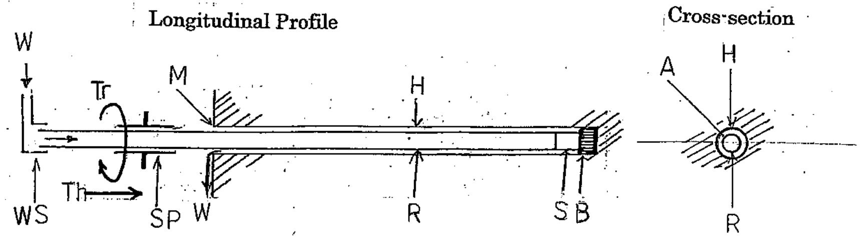


Note: The arrangement on the premise that average progress tunneling is 135 and boring is 200 m/month, respectively.

Fig. 6. An example of arrangement of exploratory boring in tunnelling.

Conventional boring system

Longitudinal Profile Cross-section



Legend

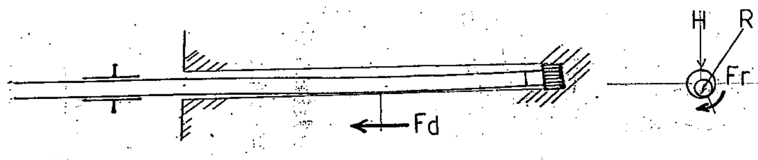
B: Bit , S: Shank, R: Rod, SP: Spindle, WS: Water-swivel,

H: Bore- hole, M: Mouth of the hole,

W: Water (normal circulation), Th: Thrust, Tr: Torque

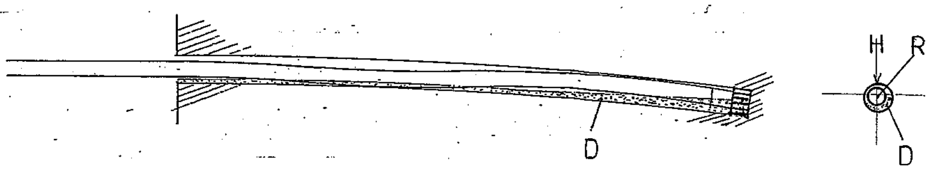
A: Annulus (between hole and rod)

Deflection of rod by gravity or thrust force



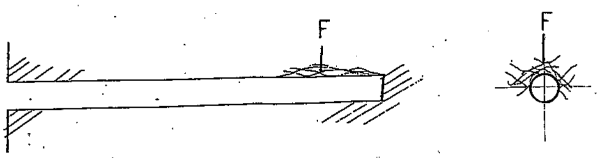
Fd: Friction on boring- direction Fr: Friction on rotary direction

Sedimentation of cuttings on lower part of the hole



D: Dust (cuttings)

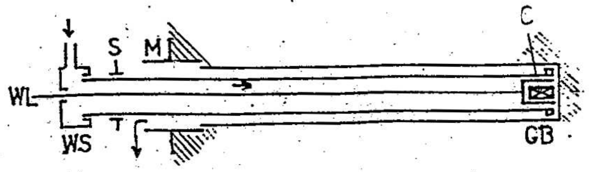
Failure of circumference of hole



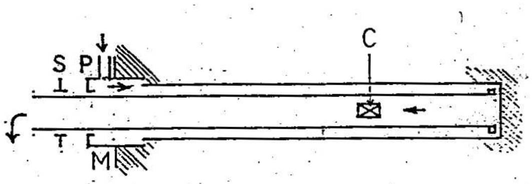
F: Failure

Fig. 7. Obstacles in horizontal boring.

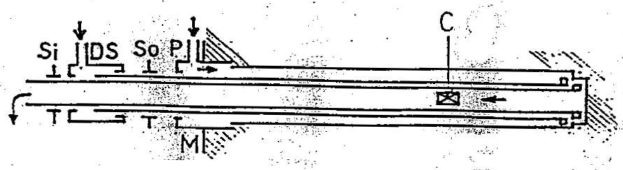
(1) Conventional system with wire-line (normal water- circulation).



(2) Reverse water- circulation system with single tube.



(3) Reverse water- circulation system with double tube.



Legend

M: Mouth pipe, C: Boring core, S: Spindle, WS: Water- swivel, WL; Wire- line
CB: Core- barrel, P: Preventer, So; Spindle for outer tube, DS; Double swivel,
Si: Spindle for inner tube, —▶ : Water flow (circulating direction).

Fig. 8. Boring- systems for exploratory in horizontal direction.

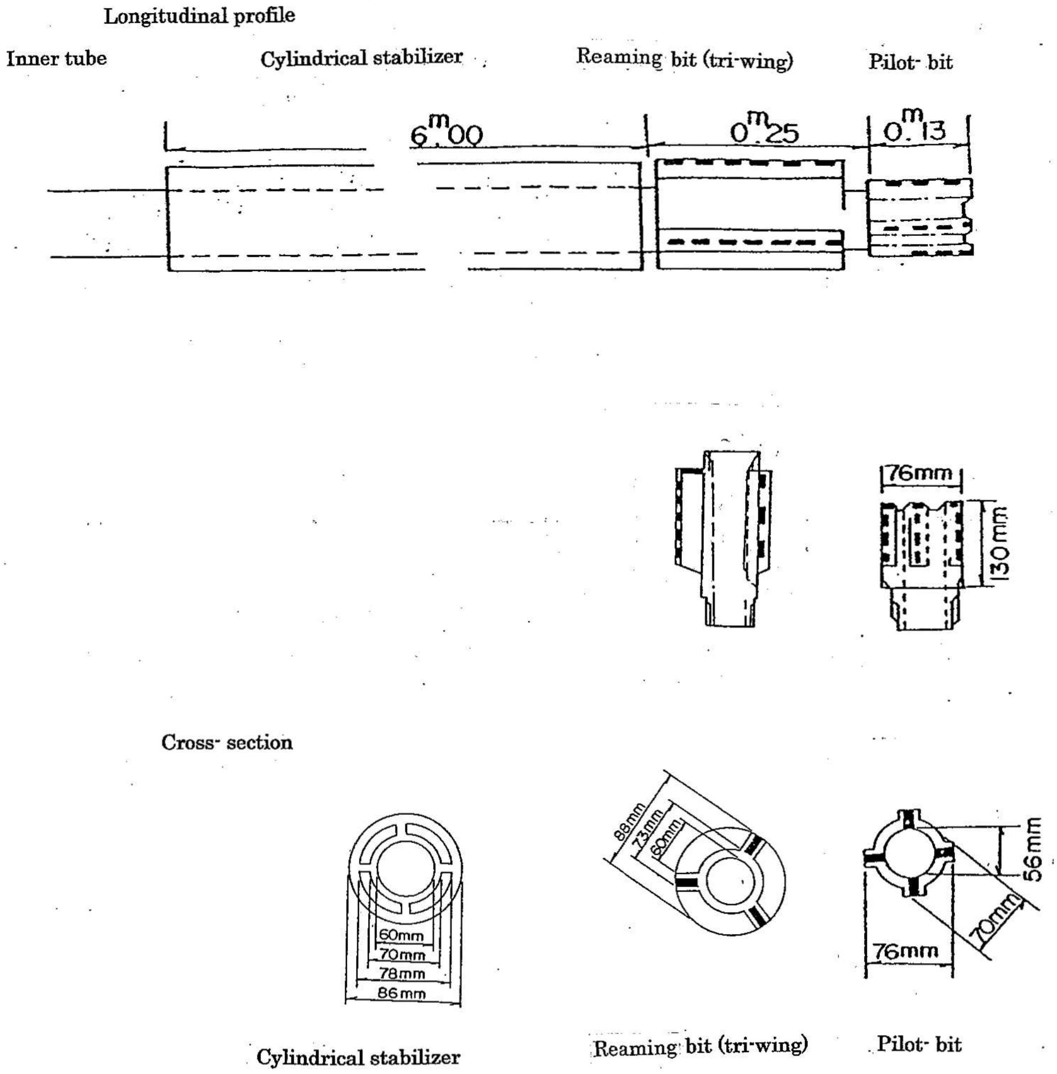
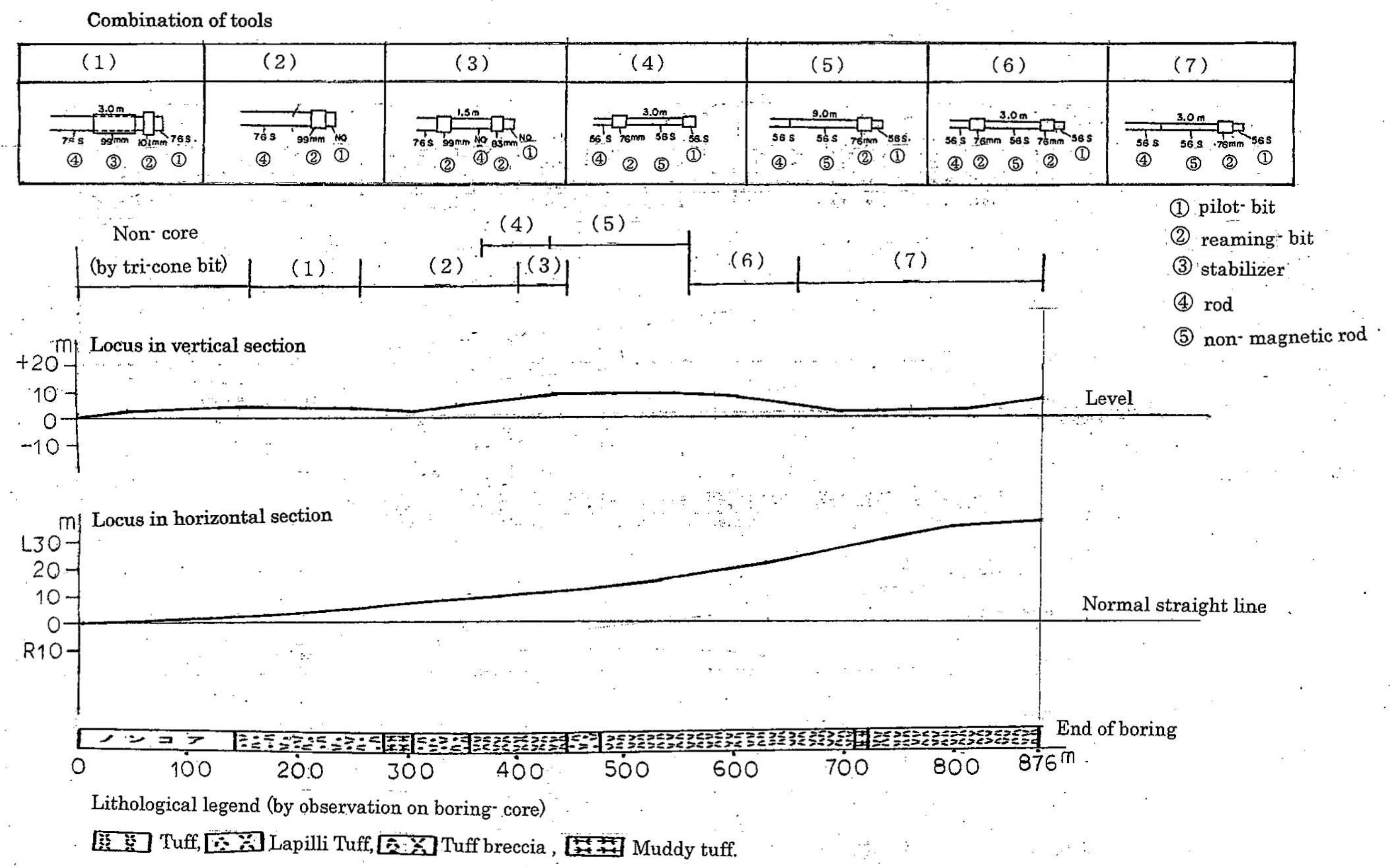
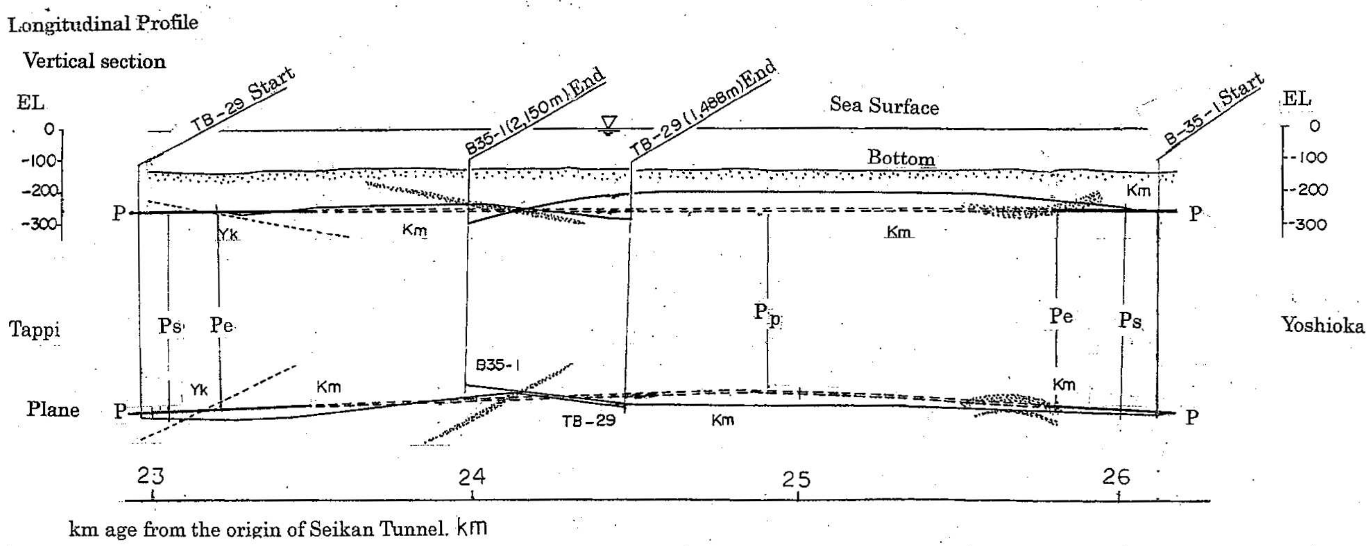


Fig. 9. An example of combination of bits and stabilizers.



Note: The locus was calculated based on results measured direction of bore-hole.

Fig. 10. An example of locus of hole bored (reverse circulation with single tube).



Legend

P: Pilot Tunnel route, ====: Section un-tunneled on the day boring end, Pp: Point pierced Pilot Tunnel,

Pe: Face tunneling on the day boring end, Ps: Face tunneling on the day boring start,

Yk: Yakumo Setaratum; much of schistosity and cleavage, Km: Kuromatsnai

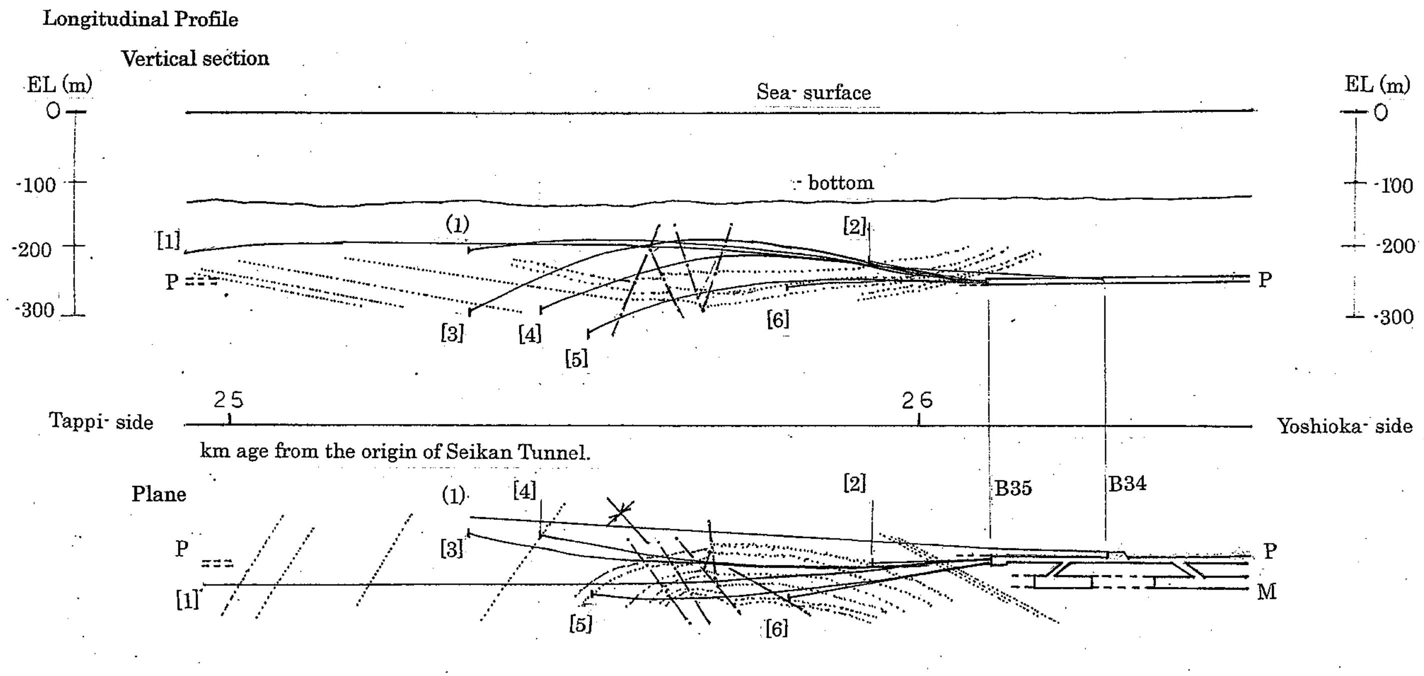
: weak layer with laminates of unconsolidated sand,

Boring data

Name	Machine	Day starting	Day ending	Inflow-water at ending	Diameter and length of that section in hole
TB-29	Fs-60C	1980.11.26	1981. 2.10	4.0m³/min. 2.5MPa	186C(35),142C(144),117C(321),101B(680),76B(308)
B-35-1	TOP-LS.	1980.12. 8	1981. 3. 3	2.5m³/min. 2.5MPa	203C(15),186C(170),135C(327),105C(1065),82B(573)

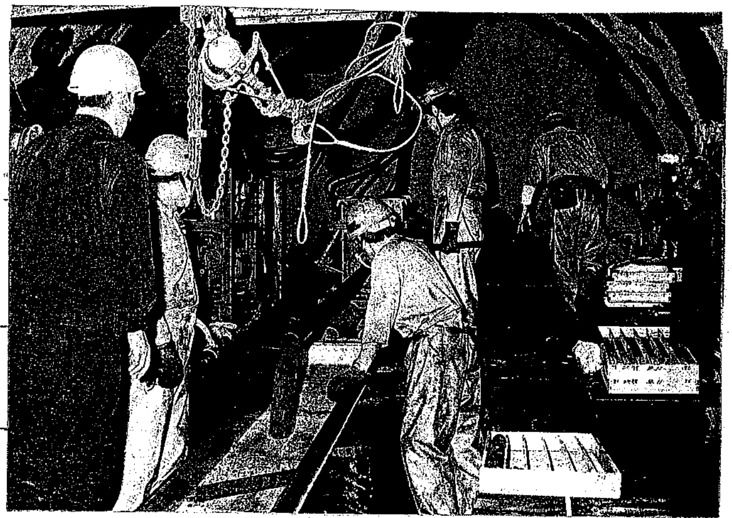
Note: Both bored by method of reverse water- circulation with single tube. Column of "Diameter and length of that section in hole" as followings.
The number not parenthesed is diameter in mm unit. The number parenthesed is length of section with the diameter.
The letter C and B mean that boring was with and without casing- pipe, respectively.

Fig. 11. The longest borings before pilot tunnel pierced at the central portion.



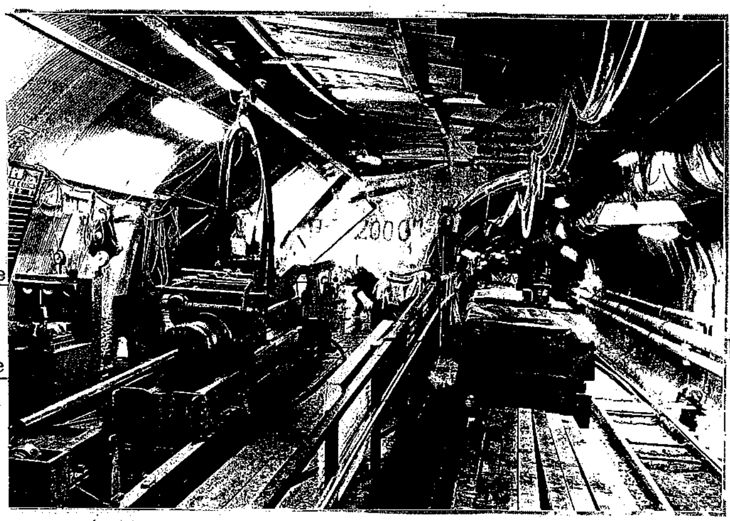
Legend
P: Pilot Tunnel, M: Main Tunnel under construction,
B34: No.34 Base for exploratory boring in Pilot Tunnel of Yoshioka- section,
B35: No.35 Base for exploratory boring in Pilot Tunnel of Yoshioka- section,
(1): Boring from B34 in long range of 953m, [1]: Boring from B35 in long range of 2150m,
[2], [3], [4], [5], [6]: Boring from B35 to survey on the structure and state of weak layers,
: Weak layer with laminate of unconsolidated sand in Kuromatsunai Strata,
: Fault in small structure, : Axis of syncline of the strata,

Fig. 12. An example of borings added to survey on the state with problem, in detail.



The position: 9k924m from the origin of Pilot Tunnel in Yoshioka-Side: 25k886m from the origin of Seikan Tunnel)

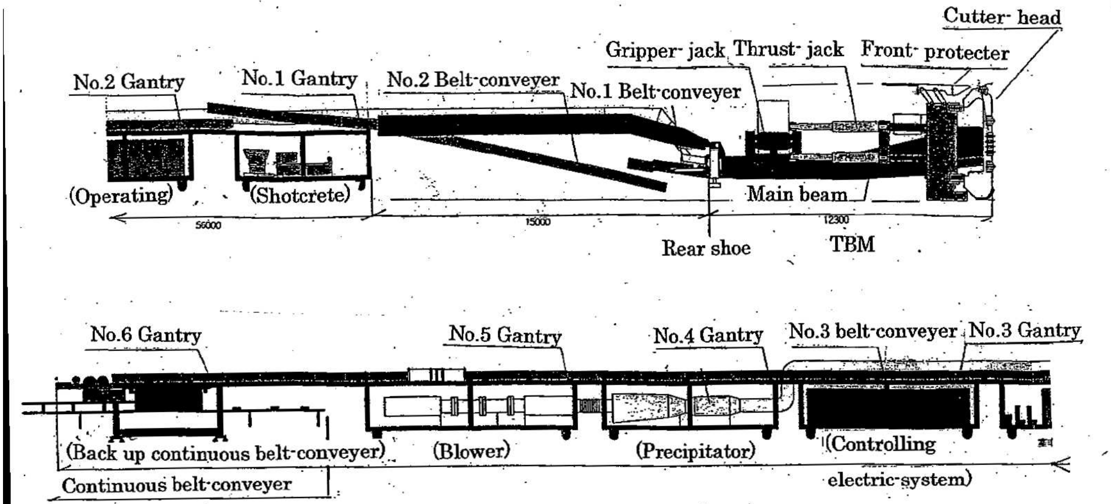
Fs-40S boring short range (final 152m) at face tunnelling in Pilot Tunnel.



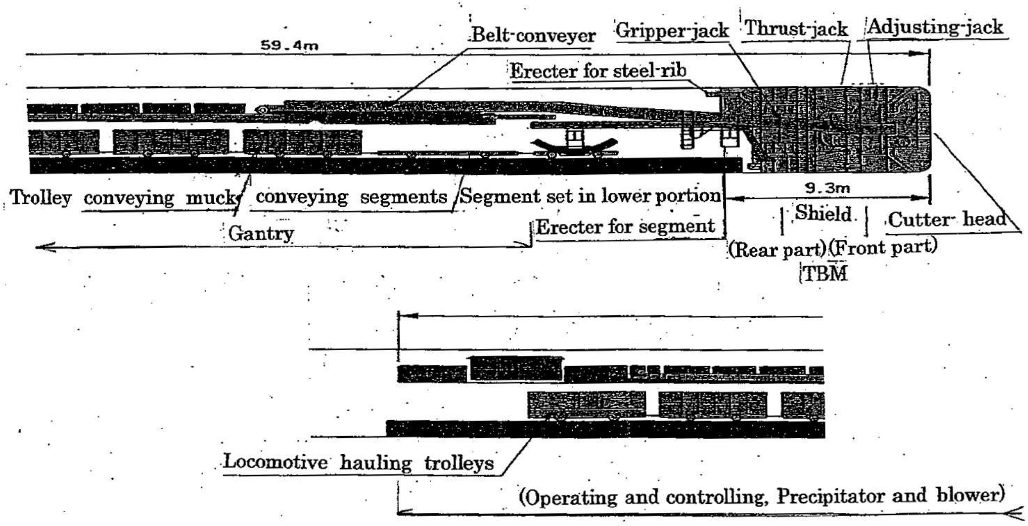
The position: 9k707m from the origin of Pilot Tunnel in Yoshioka-Side: 26k102m from the origin of Seikan Tunnel)

TOP-LS boring long range (final 2150m) in alcove (B35) by Pilot Tunnel.

Fig. 13. Example of machine appropriated to long horizontal exploratory boring.



An Example of the Equipments arranged in TBM System without Shield



An Example of the Equipments arranged in TBM System with Shield

Fig. A1 Longitudinal Profile of TBM System arranged.

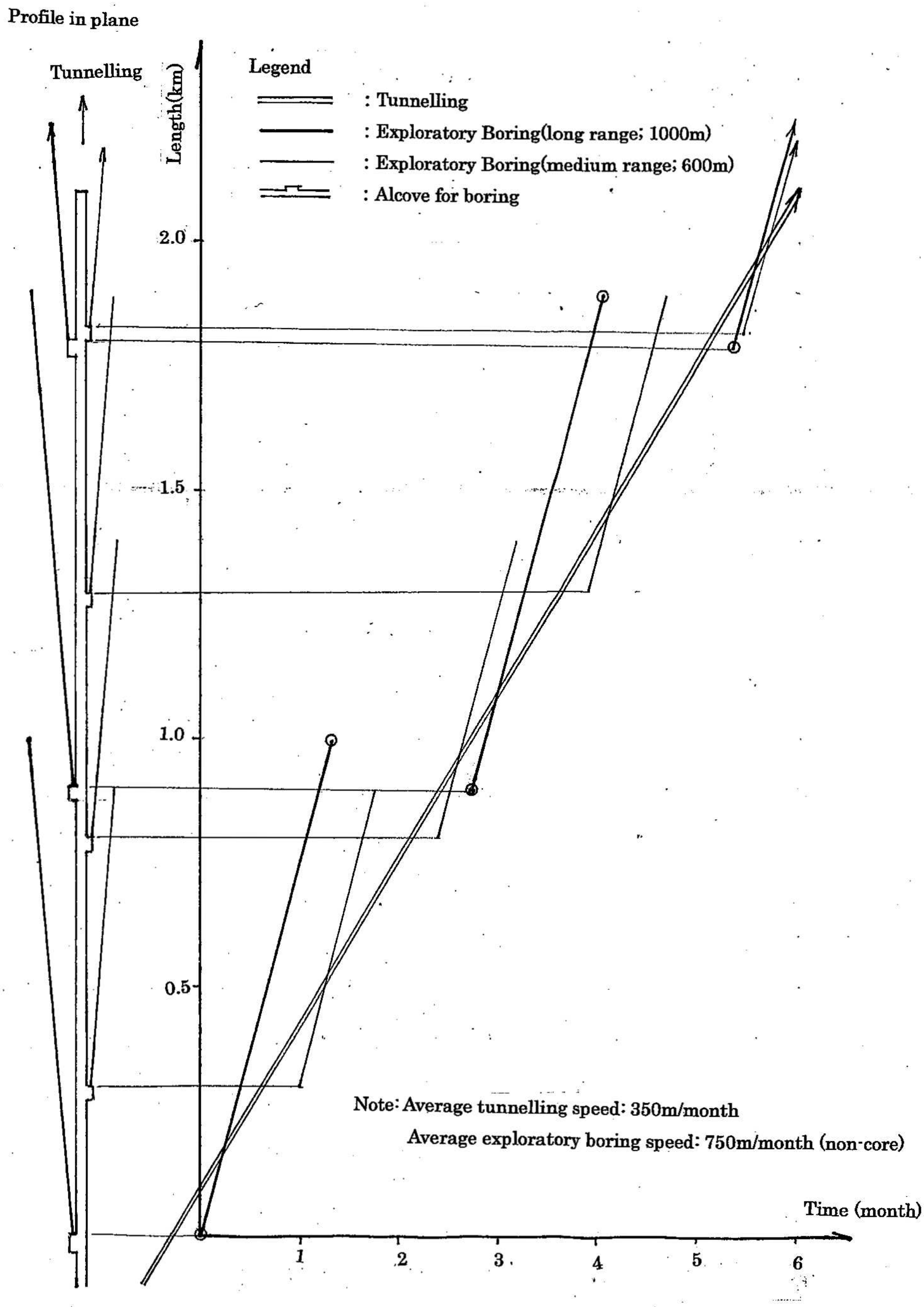
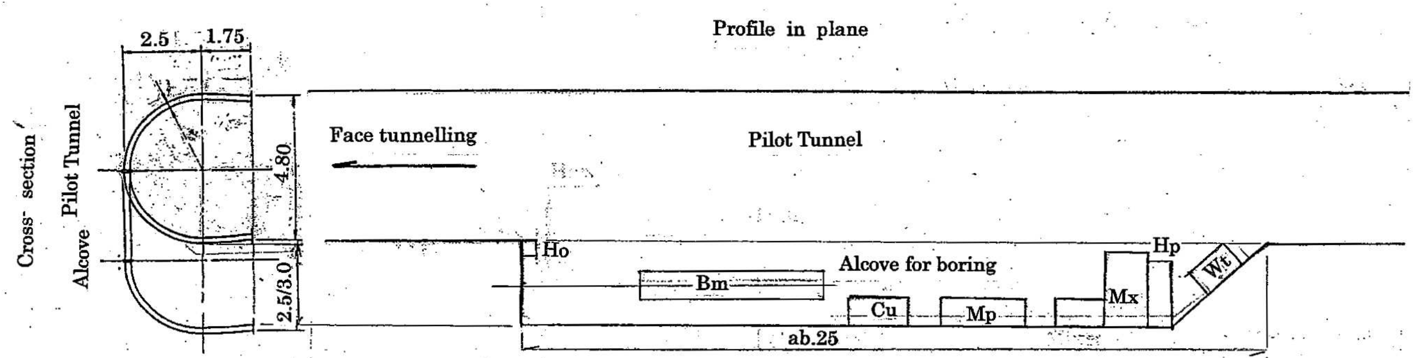


Fig. A2. An example of exploratory borings arranged both side of tunnelling.



Legend

Bm: Boring machine (drill), Cu: Control unit, Hp: Hydraulic pump unit, Ho: Hoist,
Mp: Mud-slush pump, Wt: Water tank, Mx: Mixer,

Note 1: The example is exploratory boring for long range in Seikan Tunnel.

2: The alcove was constructed with widening Pilot Tunnel.

Structural Diagram of TOP-LS Horizontal Drill

(Unit : mm)

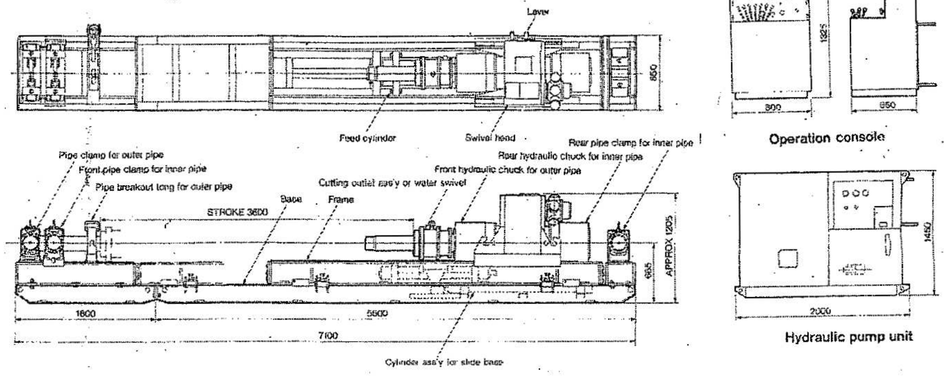
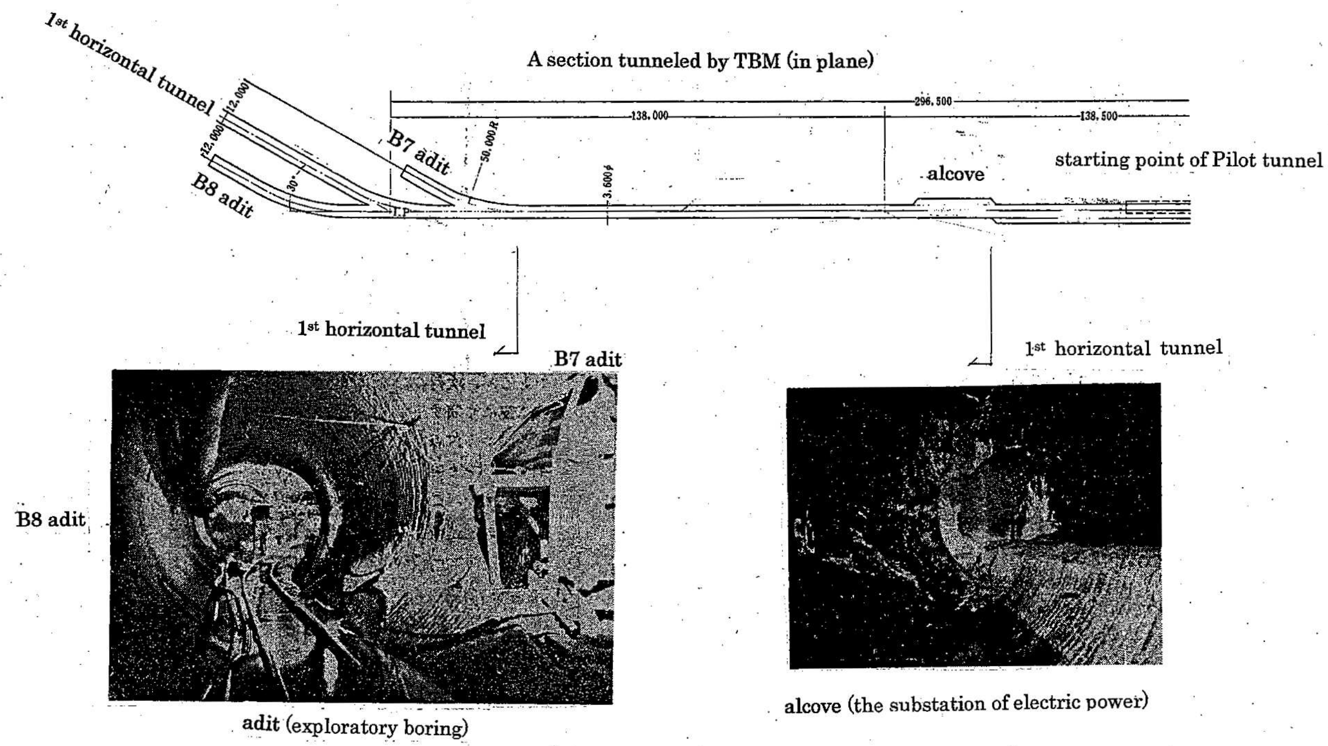
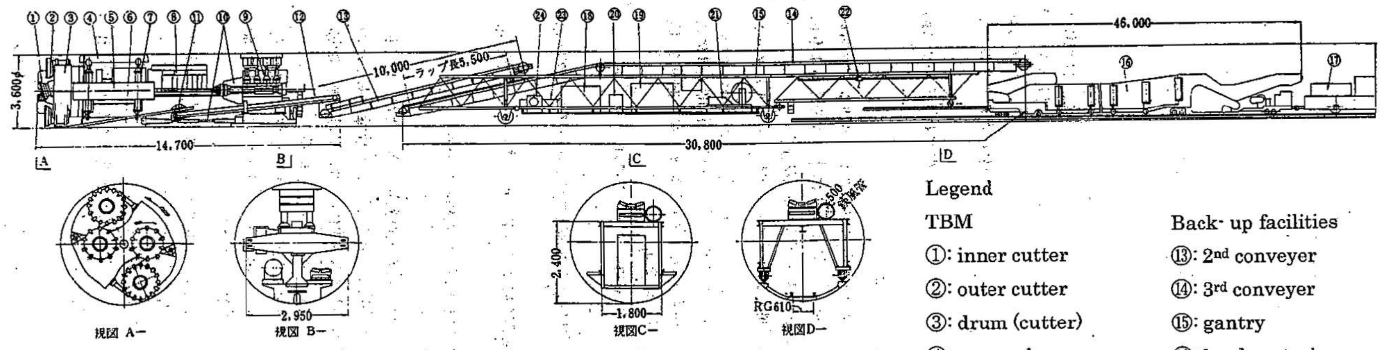


Fig. A3. Example of arrangement in alcove for exploratory boring.



Note: TBM (Wohlmeyer 736 type) excavated 1st horizontal tunnel (Pilot tunnel) and set alcove and adit on the side, in Yoshioka section of Seikan Tunnel, 1967.

Fig. A4. Example of alcove and adit set by TBM.



Note: TBM (Wholmeyer 736 type) set in 1st horizontal tunnel (Pilot tunnel) in Yoshioka section tunneled from 1967 to 69.

Fig.Acf. A TBM - Profile in Vertical section.

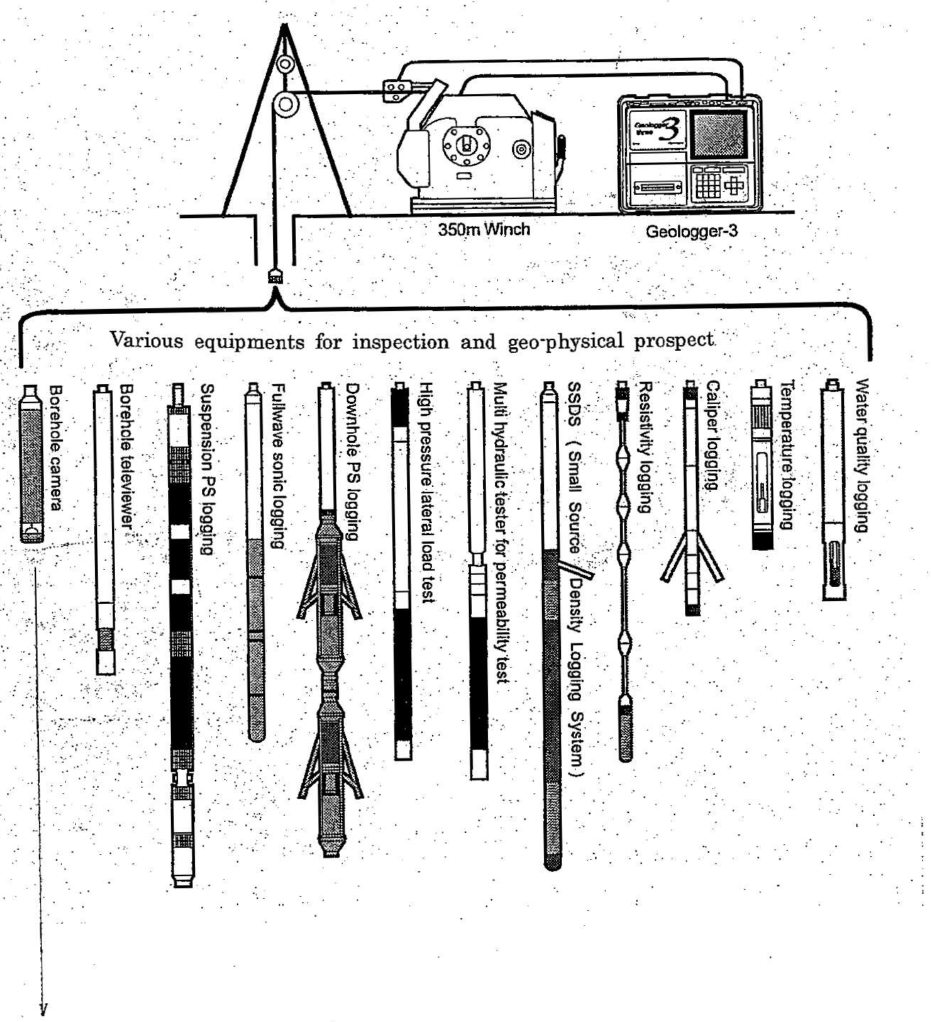
Legend

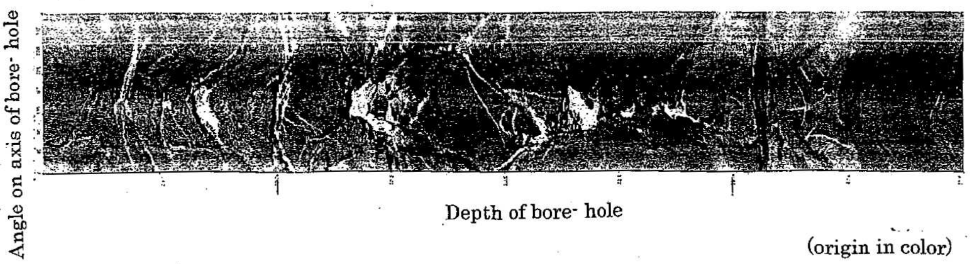
TBM

①: inner cutter
②: outer cutter
③: drum (cutter)
④: upper shoe
⑤: side shoe
⑥: lower shoe
⑦: jack- support
⑧: electric distributor
⑨: jack- press
⑩: jack- thrust
⑪: scraper
⑫: conveyer- belt

Back- up facilities

⑬: 2nd conveyer
⑭: 3rd conveyer
⑮: gantry
⑯: banker- train
⑰: locomotive
⑱: electric trans (TBM)
⑲: electric trans (banker- train)
⑳: electric trans (general)
㉑: drum (cable high voltage)
㉒: hoist (setting rail)
㉓: pump (sprinkler)
㉔: winch (hauling gantry)



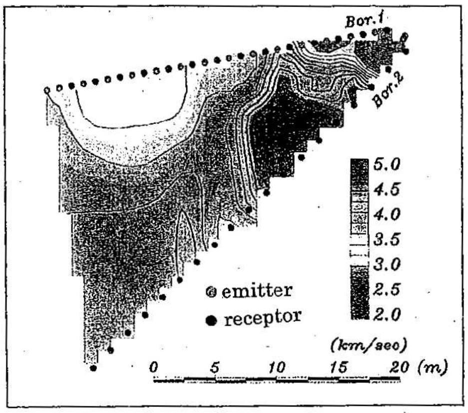


(origin in color)

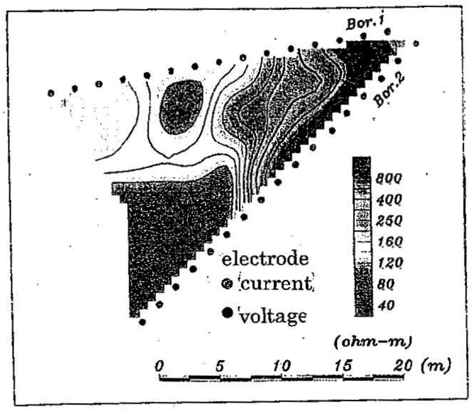
Circumference- photograph of bore- hole made from data caught by bore - hole camera.

Note: These are for vertical bore- hole.

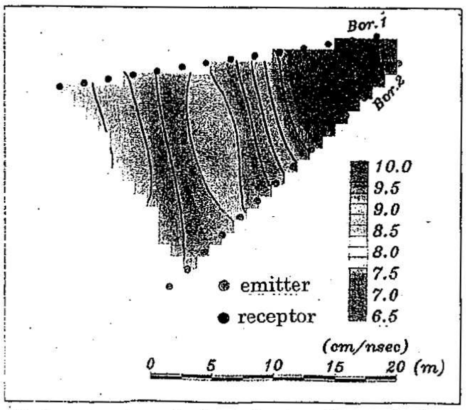
Fig. A5. Example of system logging in bore- hole.



Seismic- tomography (speed migrating seismic wave)



Electric- tomography (specific electrical resistance)



Radar- tomography (speed migrating radar)

Bor.: bore- hole

Fig. A6. Examples of geo- tomography used bore- holes. (all origin in color)