Chemical Plug Shield method

1. At the beginning

Chemical Plug Shield method (called as CPS method) is mud pressure type shield method for high groundwater pressure which Konoike Construction Co., Ltd. and Komatsu Ltd. developed jointly. Mud pressure type shield method is a superior method of construction, because the range of applicable soil is wide, advancement speed is fast and ability for excavating in boulder is high. However it is difficult to excavate in sand or gravel layers with high groundwater pressure. The CPS method is able to excavate surely safe in the ground with groundwater pressure of 2-10kgf/cm^2 without remodeling mud pressure type shield machine.

This report describes contents of research and development and technical points. An example of excavation with this method in a gravel layer with groundwater pressure of 3.5kgf/cm^2, which completed in April 1994,is also described.

2. Development of the CPS method

2.1 Development policy and technical problem

High groundwater pressure is acted on a face for excavation can induce blowing of soil and groundwater from screw conveyor muck discharging gate followed by collapse of the face. Measures such as a rotary valve and long screw conveyor installed at muck discharging gate are taken to prevent blowing. The Measure features of the CPS method is that excavated soil with high fluidity by mixing with excavation additive which called as mud making agent is improved by using additive in the screw conveyor and the improved soil is used for forming cut-off plug to oppose the water pressure at the face in latter half part of the screw conveyor. Technical development themes to enable this are listed as follows.

(a) Development of additive for improving soil for a short time (for ten and less than several seconds) which can be used for shield execution.

(b) Development of the screw conveyor in which excavated soil and additive are mixed and improved.

(c) Development of the screw conveyor which can form cut-off plug to oppose the face with water pressure by placing improved soil in its latter half part.

The flow of development is shown for Fig.1.

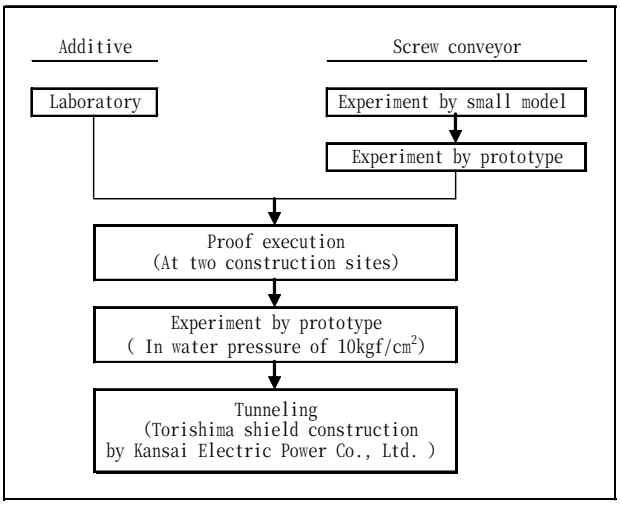

Fig.1 Development flow

2.2 Development of additive improving excavated soil

The aim of soil improvement is to make soil with non-fluidity from excavated soil mixed with mud making agent within ten several seconds. The additive for soil improvement was developed by investigating mainly on macromolecule system cohesion agent and high water absorbing polymer, and by using natural macromolecule (polysaccharides) in cooperation with a chemical maker. This is powdered agent which can make soil without fluidity from excavated soil within ten several seconds by making 1.0-2.0kg per 1.0m^3. It is necessary to prevent absorbing water / the absorbency that is the characteristic to use powder for shield execution.

Mixed within mud making agent after having coated followed by adding the liquid which removes coating in the screw conveyor part, powder was able to be handled in environment of shield construction.

2.3 Experiment by small model

With φ60mm screw conveyor, it was confirmed that excavated soil could be improved by mixing with the agent in the screw conveyor. The experimental device is shown in Fig.2.

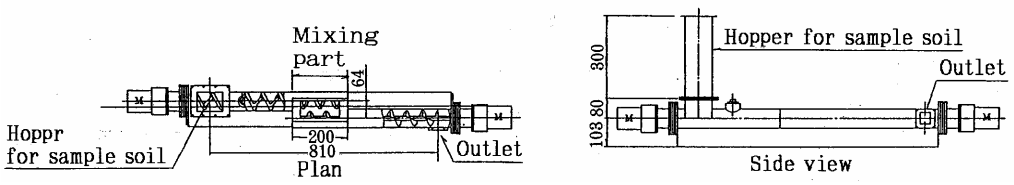

Fig.2 Miniature model of screw conveyor

2.4 Experiment by prototype

Φ300mm ribbon-type screw conveyor shown in Fig.3 was and vice-screw conveyor of the diameter were installed and the mixture part was established. The tip of the screw conveyor was inserted into the pressure tank of 1.0m^3 that imitated mixing chamber of shield machine.

The soil which imitated the shield excavated soil was cast into this, and it was able to be pressurized up to 5kgf/cm^2 by air pressure.

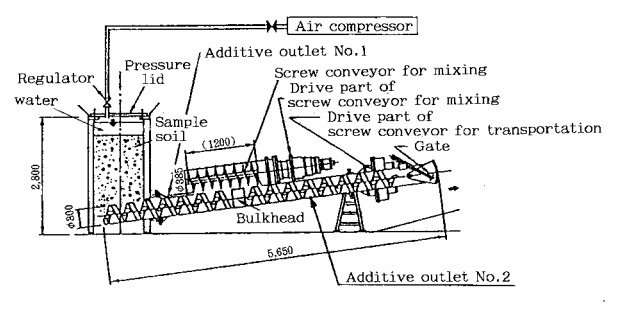

Fig.3 Experimental machine with ribbon-type screw conveyor

The additive for soil improvement, which was 1 liquid characteristic for this experiment, was injected in screw conveyor with a pump. The circumference drive type was applied for the screw conveyor and it was supposed that "trough turn confinement effect" would contribute to formation of cut-off plug.

The experiment was carried out by following the three phases listed bellow.

The first phase

Investigation for effective improving technique without pressure to the soil tank

The second phase

Confirmation of effect of cut-off plug by pressurizing the soil tank

The third phase

Establishment of an additive addition system for simplification of screw conveyor and real shield construction

Sand and gravel with water content of around 25% and mud making agent were mixed in a steel tank of 20m^3.

The results of the experiment were as follows.

①One axis screw was enough for mixing soil with additive and improving it as a ribbon-type screw conveyor.

②Because of ability of a device, pressure was added only to 5kgf/cm^2, but the cut-off plug maintained pressure surely.

Because the improved soil is compacted at the screw conveyor latter half part by trough turn confinement effect, screw conveyor with a circumference drive type can form cut-off plug to seal up a face in terms of pressure.

③Because supply oil pressure of a hydraulic motor letting drive screw conveyor becomes it more than 1.5 times at the time of improvement, whether cut-off plug is formed in screw conveyor can be judged.

2.5 Proof execution

The first proof execution was Tsukaguchi A main line shield construction in Amagasaki-shi, Hyogo. Although groundwater level was low, and this site was unsuitable for testing waterproofing pressure performance of cut-off plug, effect of main ingredient CP-M and assistant ingredient CP-S and an addition system ware established.

Successively it was demonstrated in Kano River shield construction in Numazu-shi, Shizuoka. The ground in the site was classified as sand with small gravels, in which clayey layers existed in the shape of lenses. Although the water pressure to act on a face was 1.1kgf/cm^2 degree, the quantity of groundwater was extremely abundant.

Although the effects of the CP-S method were confirmed as expected at the early stage of construction at these two sites, a couple of troubles occurred as follows at the later stage.

〈 troubles and measures - 1>

Abnormal abrasion of screw conveyor occurred. This is because the excavated soil is compacted at the end part of the screw conveyor after soil improvement in the CPS method, while highly fluid soil is transported in a standard excavation method. Although only temporary measures were taken at the site, abrasion preventive measures in the screw conveyer were taken for the next site.

〈 troubles and measures - 2>

The effect of the additive was deteriorated remarkably and excavated soil could not be improved satisfactorily at Shizuoka Kano River shield construction. It was found that the additive was neutralized by mixing with sulfur existing in the groundwater, which flows from a volcano.

For measures, an electric charge of the additive was reinforced, so that improvement ability could maintain even if sulfur was absorbed.

As a result, the expected purpose was able to be achieved.

It was had realized that investigation of groundwater (especially for ion contents) is necessary prior to the shield construction.

2. 6 Resist pressure examination

A resist pressure examination for cut-off plug was carried out with the device which could trigger the water pressure of 10kgf/cm^2. An experimental device is shown in Fig.4 and Fig.5. The materials used in the experiment are shown in table -1.

Results of the experiment are shown in Fig.6.

The inside pressure shown in the second table imitated the pressure acting on the mixing chamber of shield machine.

Pressure of 8-10kg f/cm^2 was maintained, and stable muck removal was possible even if the muck removal gate was fully open.

This shows that cut-off plug acts against the water pressure of 10kgf/cm^2 effectively.

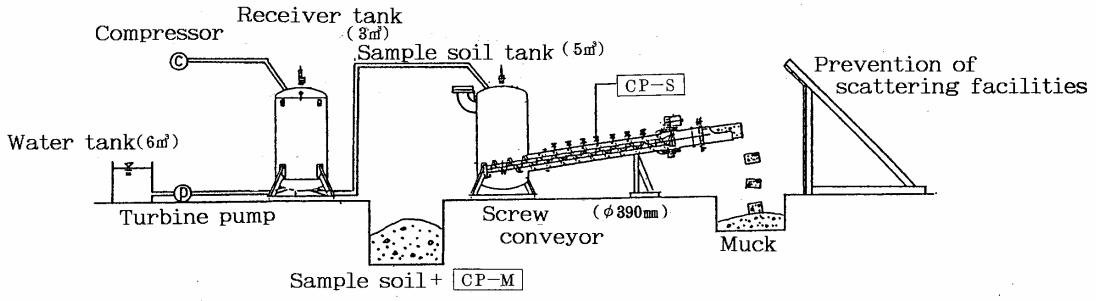

Fig.4 Experimental apparatus

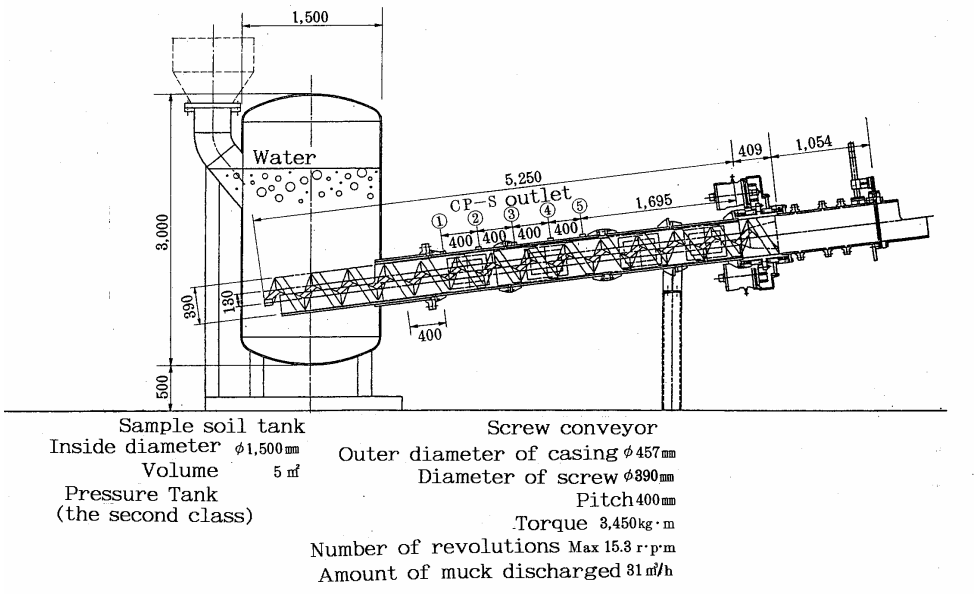

Fig.5 Screw conveyor and sample soil tank

Table -1 Use materials

Sand	Mountain sand (Tarumi-ku, Kobe-shi product)
Gravel	Pit gravel (Tarumi-ku, Kobe-shi product)
Bentonite	Izumo bentonite (# 300)
Clay	Kasaoka clay (# 200)
Sample soil	Materials shown above are mixed Slump : 23～25cm Water content : 20～25%

3. Features and application range of Chemical Plug Shield method

3. 1 Summary and additive addition system

System summary of Chemical Plug Shield method is shown in Fig.7.

A mud pressure type is used as a shield machine and mud making agent is used as excavation additive. The CPS method improves excavated soil with high fluidity into high quality soil without fluidity by adding additive in a screw conveyor. The shield machine advances while continually forming cut-off plug opposed to the water pressure at the face by filling out the latter part of the screw conveyor with the improved soil. The additive falls into 2 categories, main ingredient CP - M which is mixed within the mud making agent, and assistant ingredient CP - S which is added in screw conveyor.

Quantity of each ingredients is adjust depending on speed of the shield jack.

1-2kg of CP - M and 0.5-1 liters of CP - S are used per $1m^3$ of excavated soil for ground with sand and gravel.

3. 2 Features and application range

(a) By the CPS method, excavation of gravel aquifers with high groundwater pressure (2-10kg f/ cm^2), which was impossible expect for slurry type shield method, is possible.

(b) Depending on a geologic change, the CPS method can be changed to mud pressure type shield method easily by stopping use of the additive CP - M and CP - S.

(c) Application ground

①Most suitable for a aquifers with gravel and high groundwater pressure.

②Also applicable for clayey ground with gravel aquifers.

③Also applicable for ground with cobble stones.

④ Applicable up to groundwater pressure of $10kgf/cm^2$.

(d) It can be difficult to maintain the performance of the CP - S method in the ground obstructing the effect of the additive CP - M and CP - S.

①The ground where groundwater became strong alkalinity chemical grouting.

②The ground where groundwater became strong acidity by volcanic ejecta

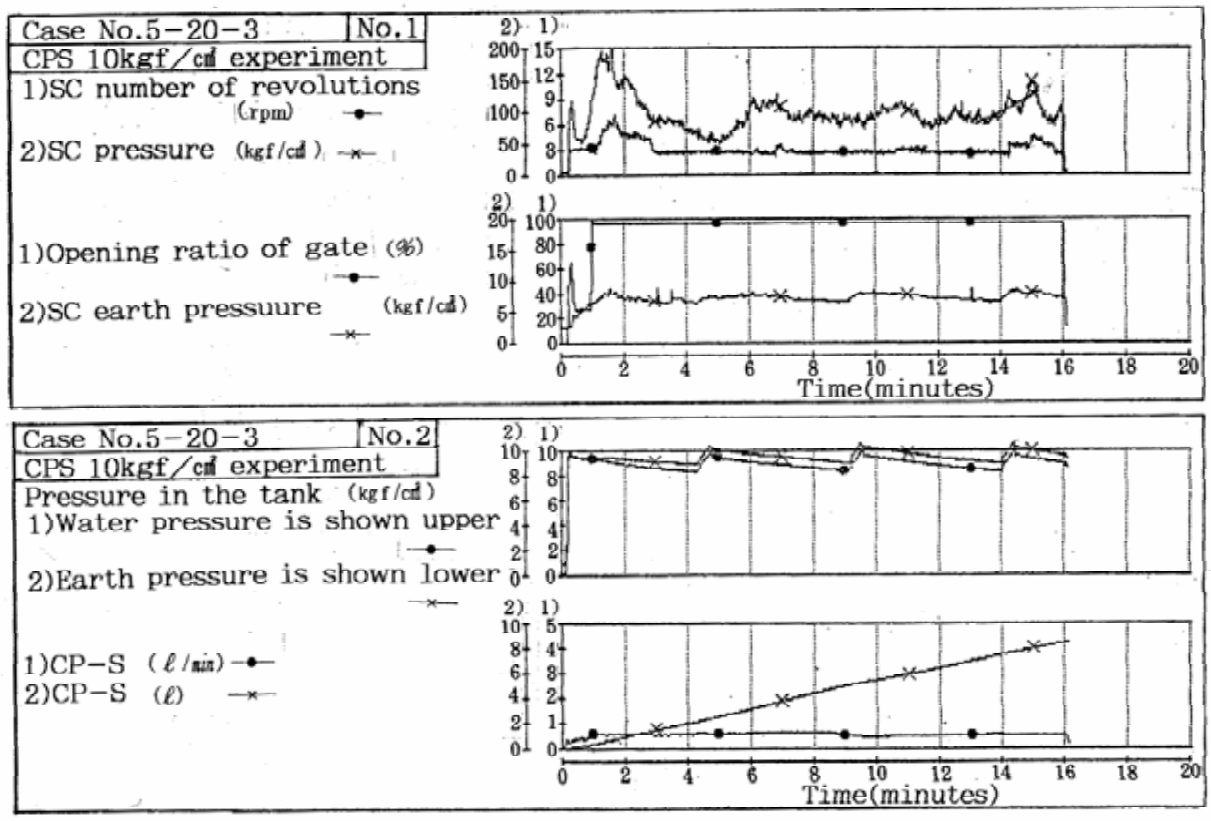

Fig.6 10kgf / cm² pressurization test data

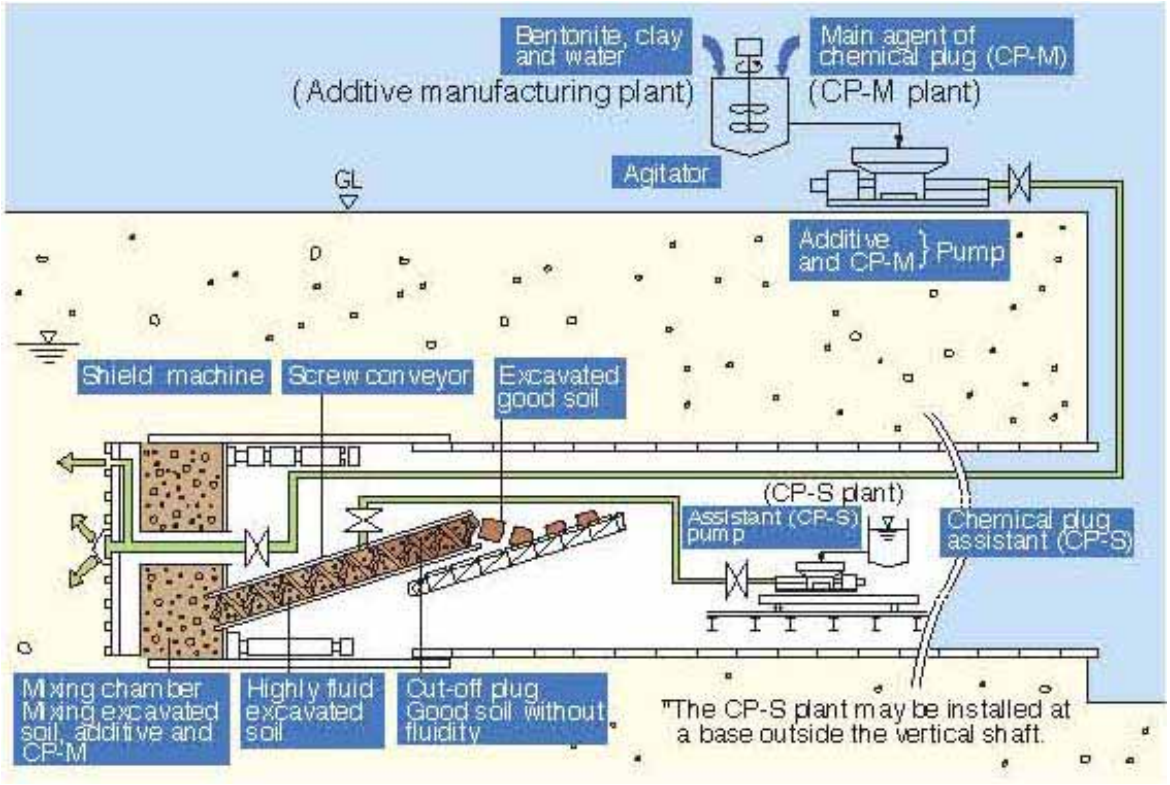

Fig.7 System summary for CPS method

4. Practical example (application to gravel layer with groundwater pressure of 3.5kgf/cm²)

4. 1 Construction summary and geological condition

The summary of construction is shown in table -2. The location of the site is shown in Fig.8. The geological section along the route is shown in Fig.9. In this site alluvial layer with sand any clay are found from the ground level to OP-32m.

This shield tunnel was constructed mainly in the diluvial layer of thickness of 5m underneath OP-32m, which is a firm layer with large gravels up to φ 300mm and large gravel contact rate of around 60%, called as Temma gravel layer. The quantity of groundwater is abundant and the water pressure is around 3.5kgf/cm² at the center of the gravel layer.

Table -2 Construction summary

Item	Summary
Construction name	Torishima shield S/S drawer duct line new construction of the first section
Construction site place	6, Torishima, Konohana-ku, Osaka-shi ～2, Shimaya, Konohana-ku, Osaka-shi
Term of works	July, 1992～December, 1994
Owner	Kansai Electric Power Co., Ltd.
Contractor	Konoike Construction Co., Ltd. Sato Kogyo Co., Ltd. Okumura Corporation Co., Ltd. Daiho Construction Co., Ltd. construction joint venture
Shield excavation length	832m
ıter diameter of shield machin	Φ6,140mm
Finished inside diameter	Φ5,000mm
Overburden	20.7～34.7m

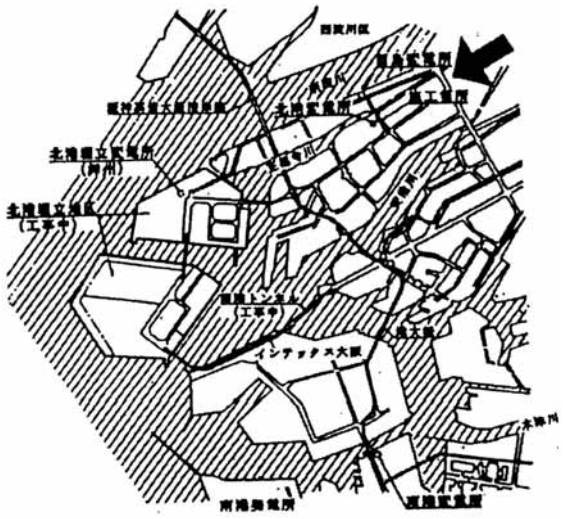

Fig.8 Location of the site

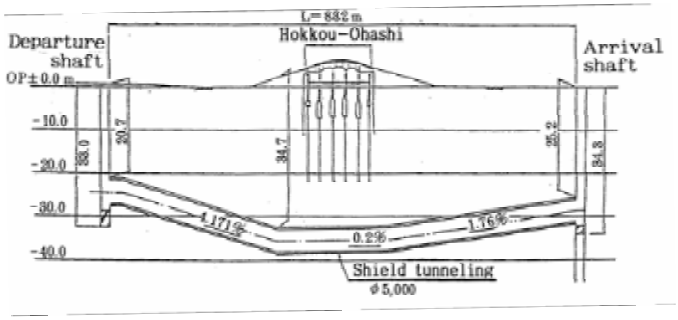

Fig.9 Geological section along the route

4. 2 Shield machine

Shield machine was mud pressure type shield machine of φ 6,140mm with cutters of spoke type, and two muck removal screw conveyors with, and φ 650mm*10.0m, and φ 650mm*12.5m, in which cut-off plug of a CPS method was formed.

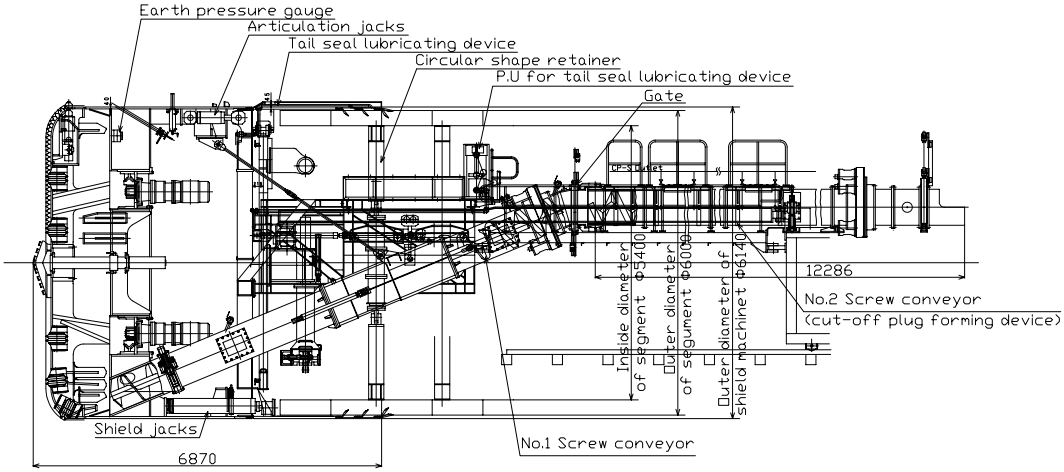

Fig.10 Shield machine of φ6,140mm

4．3 Shield machine driving process

For the first 170m from the departure shaft, where the ground type is alluvial, the additive was not used; the mud pressure type was applied. Just before excavating into the gravel layer, the CPS method was applied. Follows are the working conditions.

①Water pressure at the cutting face

3.5-3.7kgf/cm^2 at the shield machine center

②Advance speed of the shield machine

40mm / min

③Excavation additive

10-15% of the mud making agent with 100kg of clay, 200 kg of bentonite and 887 litters of water, for 1.0m^3 of excavated soil.

④The additive for soil improvement

2.5kg of CP-M, 2 liters of CP-S for 1.0m^3 of excavated soil.

For maintaining the pressure on the face, the quantity of discharged soil and advance speed of the shield machine was controlled. The screw conveyor muck discharging gate left fully open.

Fig.11 shows driving data for advance of one segment ring. The oil pressure of the second screw was around 100kgf/cm^2, which shows that the formation state of cut-off plug was as expected.
The rotational frequency of screw conveyor was fixed to 12r.p.m.

The earth pressure at the face was maintained over 3kgf/cm^2. The reason why the earth pressure gauge was fluctuated is supposed that the soil was agitated by rotation of the cutter.

Jack speed almost showed 40mm/min.

The CPS method was applied for 600m of Temma gravel layer with high groundwater pressure out of 832m of total length. The face water pressure was maintained, and consecutively the tunnel constriction was executed in normal advancement speed without generating blow.

4．4 Other achievements

Besides three spots (Tsukaguchi A main line shi eld construction in Amagasaki-shi / Kano River sh ield construction in Numazu-shi / Torishima shield construction by Kansai Electric Power Co., Ltd.) mentioned in this report, three other tunnels by other companies (Nagaoka waterway construction for canceling snow /Chikuma River basin sewerage / Azusa River siphon shield construction) and one tunnel by our company (Hyogo West Himeji second shield construction) were completed.

Adoption of this method in subway shield construction of Kobe-shi is planned.

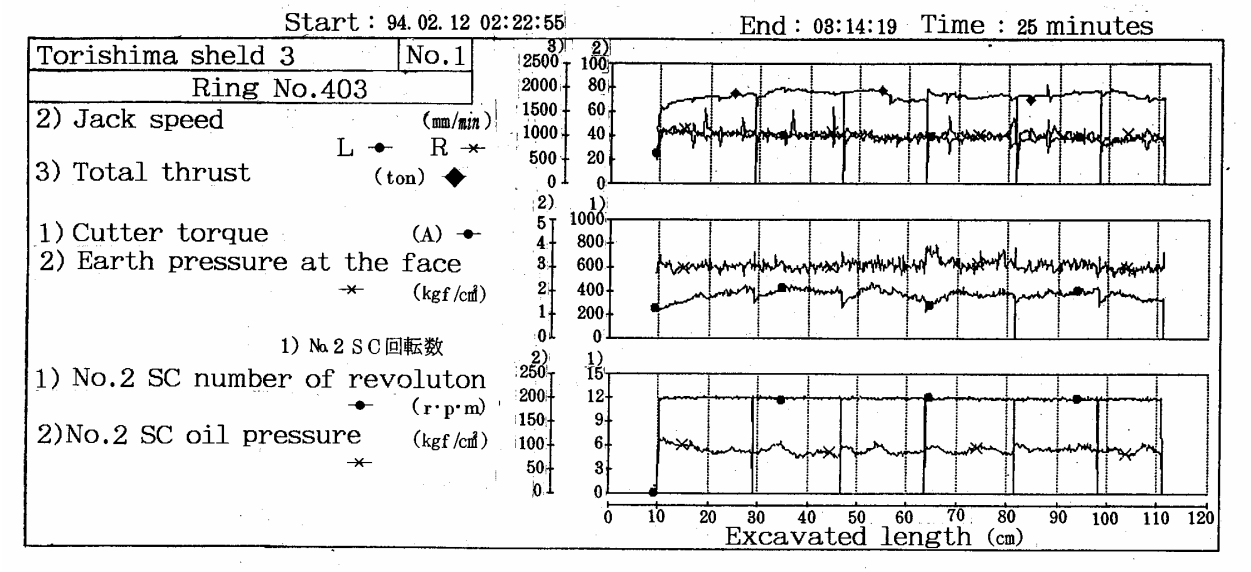

Fig.11 Driving data for advance