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Development of shield machine for Mechanical Shield Docking method (Part 1)

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ABSTRACT: We have developed a new shield docking method called the Mechanical Shield Docking (MSD) method. In the MSD method shield machines have the special equipment for docking, and connect to each other mechanically.

During the development of the MSD method, experiments have been carried out for the purpose of estimating the sealing performance, excavatability, and face stability for MSD method. As a result, it was confirmed that the shield machine for MSD method has high performance and the MSD method has been put to practical use.

1. INTRODUCTION

Recently notice is being taken of two kinds of frontier development as effective utilization of unutilized spaces in large cities, namely, "Water Front" and "Geo Front".

It becomes difficult year by year to secure land for constructing shield work shafts in urban areas. In addition, due to increased depth of tunnelling works related to "Geo Fronts", the construction cost and time will be vast. For the undersea and under-river shields construction of their shafts themselves may be considered to be very difficult in some cases.

For the purpose of solving the above problems increase of the tunnel length, that is to say underground docking of shield tunnels is highlighted, together with its shortening of construction periods.(1)

Conventionally, underground docking has been commonly with the application of the chemical injection method or freezing method, which hardens the ground around the excavation face to prevent ground collapse of the face top and spouting-out of pressurized ground water. The chemical injection method has some problems relating to procurement of its ground plant and preservation of environments (ecology). The freezing method has such demerits to require not only a tremendously-long construction period for preparation, freezing and defreezing but also careful sophisticated construction control for confirmation of the frozen area and prevention of ground settlement at the time of defreezing.

In order to replace such conventional methods, a new method called the Mechanical Shield Docking (MSD) method, which two shield machines facing each other dock directly and mechanically, was developed through our joint research with Shimizu Corporation.(2)(3) In the development of this method, various experiments were conducted to solve the technical problems. Their, results of the experiments will be reported.

2. GENERAL DESCRIPTION AND FEATURES

In the MSD method, two shield machines, one on the penetrating side and the other on the accepting side, move ahead, excavating soil toward each other and when they meet face to face, their cutter head diameters are reduced. The steel ring built in the shield machine penetrates into the accepting room of the shield machine on the accepting side so that the two machines dock each other mechanically. The sequence of the docking method is shown in Fig. 1.(4)

(1) The two shield machines which have been moving forward from both sides while excavating stop shortly before the contact of their cutters. Their cutter head diameters are reduced in the

extensible spoke mode while a earth or slurry pressure is applied from inside the shield machines to the excavation face, and shield machines are driven ahead while the cutter heads are pulled to slide into the chambers.

(2) The penetrating steel ring built in the hood section of the shield machine on the penetrating side is inserted with a pressure into the accepting room of the shield machine on the accepting side. Then, the penetrating ring joins with the pressure receiving rubber ring (in the accepting room), holding the pre-determined contact pressure.

(3) The shield machines are disassembled and removed except for the docking section, and the secondary concrete lining is placed.

The structure of the MSD method shield machine differs from that of the conventional shield machine as follows:

(1) The mechanical docking device is built in the hood section of the shield machine. The shield machine on the penetrating side contains the penetrating ring, ring room to contain this, and hydraulic jacks to push this. The shield machine on the accepting side contains the pressure receiving rubber ring, penetration accepting room to contain this, and hydraulic jacks to pull this in.

(2) The extensible cutters are fitted. Because of these cutters and the docking mechanism, the shield machine for the earth pressure balanced type MSD method does not have a circumferential ring at its cutter heads. (The circumferential section of the cutter face plate for the slurry type MSD method shield machine.)

(3) The slide mechanism is fitted in order to contain the cutter head into the chamber. However, this mechanism is fitted for the purpose of decreasing the distance between the shield machines as far as possible and decreasing the length of the penetrating ring (and its driving mechanism), and this is not always necessary to this method.

3. OBJECTIVES AND HISTORY OF DEVELOPMENT

The objectives to develop the MSD method are as follows:

(1) This method could achieve the easy control of the underground docking and shorten the construction period without disturbing the natural ground around the shield machines.

(2) This method has the high water cut-off performance at the joint section.

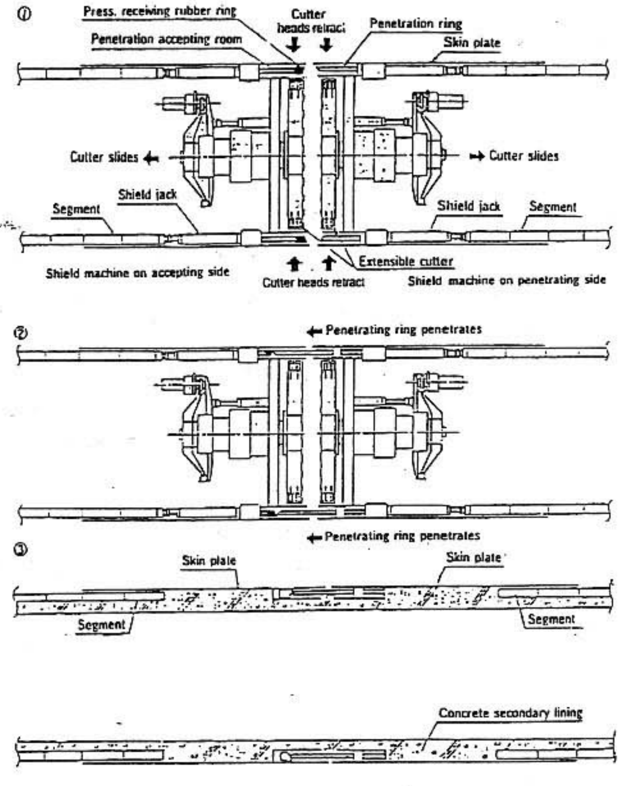


Fig. 1 Process of MSD shield machine docking
After the cutter head diameter has been reduced, the penetration ring is inserted into the accepting room to accomplish the docking.

(3) The MSD shield machine

(i) is applicable to both shield methods of the slurry type and earth pressure balanced, and

(ii) has the performances and operability similar to those of the conventional machines.

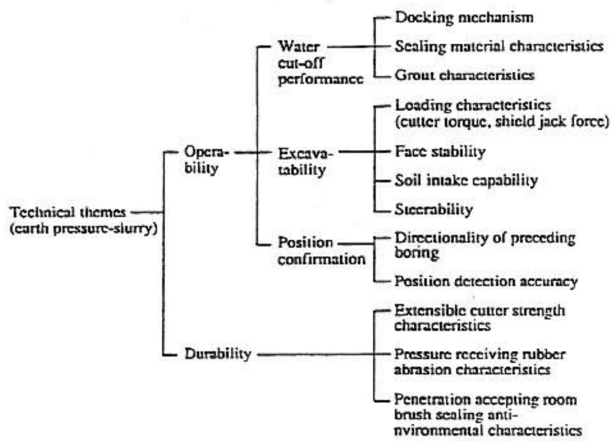


Fig. 2 Technical themes for developing MSD method
The technical problems studied in the development of the MSD method are shown.

From the view point of above development objectives, the technical problems to be solved (Fig. 2) were considered and various fundamental tests were carried out since 1986. On the basis of the data and results of these fundamental tests the slurry type MSD method shield machine of 3,470 mm in excavation diameter (for the demonstration test) and the earth pressure balanced type machine of the same diameter (for the practical work durability test) were designed, manufactured and put into the excavation and docking tests.

4. RESULTS OF DEVELOPMENT

4-1. Fundamental Joint Section Water Cut-off Performance Test

4-1-1. Outline

At the time of underground docking, the joint section should have a sufficient water cut-off performance against the surrounding earth and water pressure. Therefore, in order to obtain the basic data required in the study of the joint section construction, the water cut-off performance test was conducted, using sealing materials types and layout as parameters.[4]

With the pressure resistance target value set at 0.8 MPa, the relation between the water pressure and water leakage rate was to be obtained.

4-1-2. Test Method

The outline of the test device is shown in Fig. 3. The test device consists of a penetrating ring (600 mm in deameter), a hydraulic jack for the penetrating ring, a penetration accepting room provided with sealing materials, a pressure regulating valve, an air pump, etc.

As for the sealing materials to accept the penetrating ring in the penetration accepting ring, two types of materials were used, namely, natural rubber which has excellent physical properties and wire brush seals which have good performance records as the tail sealers of shield machines and have a high running performance.

Clean water was used to be cut off and supplied into the penetrating ring after the penetrating ring was inserted into the penetration accepting room and docking was completed. The inside space was pressurized with air up to 0.8 MPa stepwisely in 0.05 MPa increments and water leakage rate through the joint section were measured.

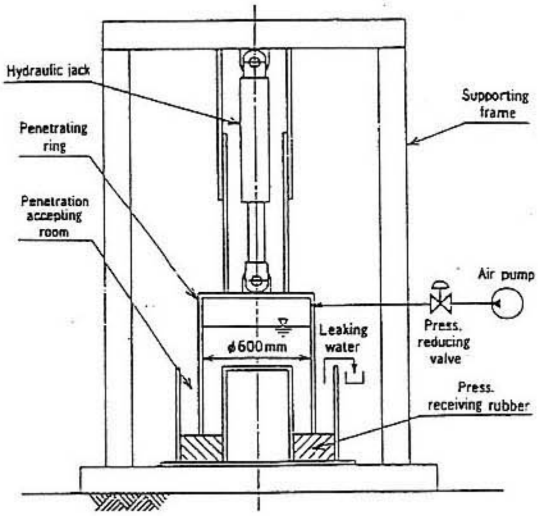


Fig. 3 Sealing performance test device
The water in the penetrating ring is pressurized and the joint sealing performance is evaluated.

In the case of the natural rubber sealant, a mixture of coarse sand, fine grained sand, and fine fraction mixed at the ratio of 5%, 77%, and 18% respectively was placed over the rubber surface to the thickness of 10 cm, the penetrating ring was thrusted thereupon to form a joint, and the water cut-off performance thereof was evaluated with a parameter of the contact pressure of the penetrating ring against the natural rubber (pressure receiving rubber).

In the case of the sealing brushes, the water cut-off performance was evaluated after the grout was injected between the brushes and into the penetration accepting room, changing the direction and layout of the sealing brushes.

4-1-3. Test Results

The test results are shown in Figs. 4 and 5. Fig. 4 shows the relation between the water pressure and the water leakage rate, the contact pressure of the penetrating ring against the pressure receiving rubber being the parameter. Where the contact pressure P is 1.3 and 1.8 MPa, the water leakage rate tends to increase acutely as the water pressure increases, but where the contact pressure P is 2.7 MPa, an excellent water sealing performance is seen up to the target water pressure of 0.8 MPa.

Fig. 5 shows the relation between the water pressure and the water leakage rate with reference to the direction and layout of the sealing brushes in the penetration accepting room. In Case 1 of this figure, the sealing brushes are placed in two tiers in

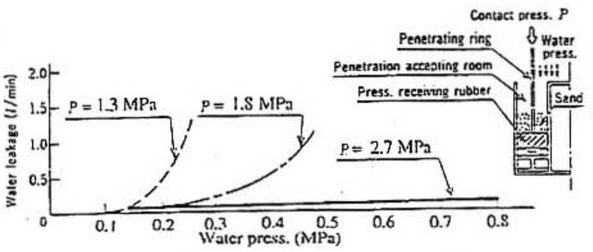


Fig. 4 Relation between water pressure and water leakage (natural rubber)

Where the contact pressure P is 2.7 MPa, an excellent sealing performance is demonstrated up to water pressure of 0.8 MPa.

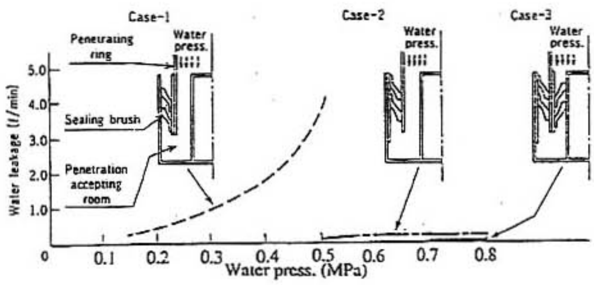


Fig. 5 Relation between water pressure and water leakage (sealing brush + grout)

Where the brushes are positioned inn the positive direction against pressurization as in Case-2 and Case-3, and excellent water cut-off performance is demonstrated up to water pressure of 0.8 MPa.

the direction opposite to the pressure: in Case 2, the sealing brushes are placed in two tiers in the direction positive to the pressure: and in Case 3, the sealing brushes are placed in two tiers each on both inside and outside of the penetrating ring in the direction positive to the pressure. Those three cases were subjected to testing. In Case 1, the water leakage rate tends to acutely increase as the water pressure increases, because the sealing brushes are positioned in the direction opposite to the pressure. On the other hand, in both Cases 2 and 3, high water sealing performances are recognized up to the target water pressure of 0.8 MPa.

Accordingly, it is confirmed that a sufficient water cut-off performance can be obtained up to the target water pressure of 0.8 MPa, when, in the case of the rubber sealing, the contact pressure of the penetrating ring is kept above 2.7 MPa, or when, in the case of the sealing brushes, two or more tiers of the sealing brushes are placed in the direction positive to the pressure.

Now, for the construction of the penetration accepting room in the joint section either or combination of the following two types is considered:

(1) Construction where the end of the penetrating steel ring contacts the pressure receiving rubber.

(2) Construction where grout is injected between the sealing brushes and into the penetration accepting room.

4-2. Practical Work Excavation Durability Test

Through excavation in actual work the load during operation, the effect on the ground and operability, strength and durability of various machine sections for the MSD method shield machine were confirmed. Fig. 6 shows the outside appearance where the penetrating ring is extended.[5]

4-2-1. Outline of Work

Work place:	Yokohama City, Kanagawa Prefecture (Sewerage work)
Work condition:	Sandy silt, silty sand, sandy mud, and gravel (max. gravel dia.: 300 mm), N-value = 3 to 50, ground water level = GL − 2 m
Tunnel length:	760 m (Curve: 300 m R)
Cover depth:	10.35 to 11.07 m
Shield diameter:	3,470 mm
Shield type:	Earth pressure balanced type

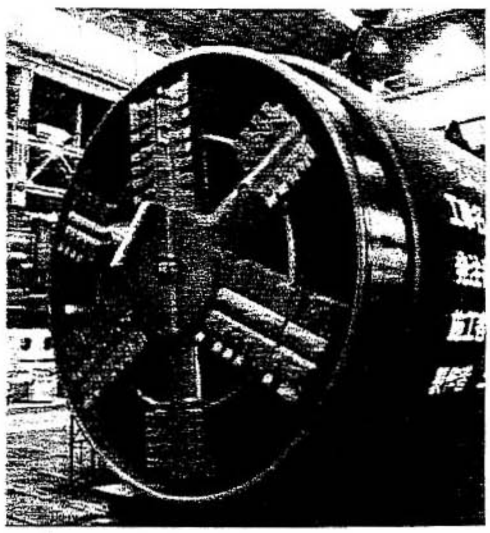


Fig. 6 ø3470 mm shield machine for MSD method

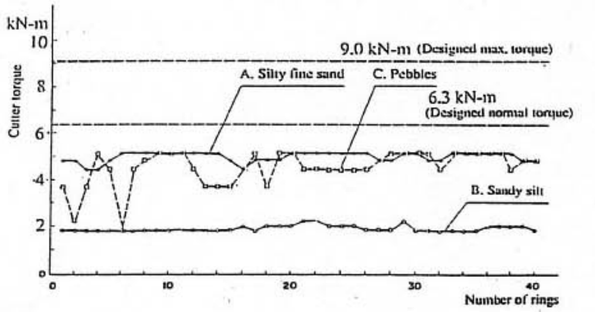
Conditions wherein the penetrating ring extended.

4-2-2. Test Results

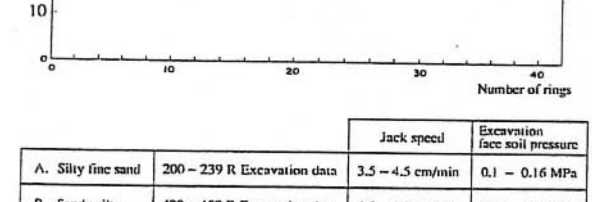
a) Excavation Performance
(Earth Pressure Balanced Type)

The excavation data of the practical work are summarized in Fig. 7 in respect to the cutter torque and shield jack force for each soil. With this figure it is confirmed that with the conventional machine equipment no problem arises from the viewpoint of both the cutter torque and jack force. As for the steerability, this machine could operate with accuracy equivalent to the conventional machine, though the curve operation was included and the soil condition varied remarkably.

Fig. 8 shows the end of shield machine at the docking point and the docking error was 20 mm only.



		Jack speed	Excavation face soil pressure
A. Silty fine sand	200 – 239 R Excavation data	3.5 – 4.5 cm/min	0.1 – 0.16 MPa
B. Sandy silt	420 – 459 R Excavation data	4.5 – 4.8 cm/min	0.13 – 0.16 MPa
C. Pebbles	700 – 739 R Excavation data	1.2 – 1.6 cm/min	0.13 – 0.16 MPa



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C. Pebbles	700 – 739 R Excavation data	1.2 – 1.6 cm/min	0.13 – 0.16 MPa

Fig. 7 Shield Jack Force Measurement Data

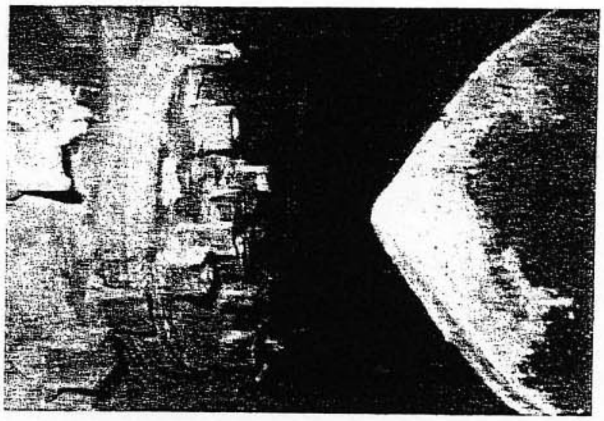

Fig. 8 End of Shield Machine at Docking Point (Right side: Worked this time)

b) Durability of Various Machine Sections

Stresses generated at various machine sections were measured with strain gages. The measured positions were important sections peculiar to the MSD method shield machine, and were 6 points in total, i.e. 4 points in the extensible cutter section plus 2 points in shield hood section as shown in Fig. 9.

In order to evaluate the measured stress data the analysis calculation for each position was carried out through the following procedures. The calculated and measured values are summarized in Table1.

(1) Cutter spoke internal cylinder (back face stress)

The cutter spoke of the MSD method shield machine has a extensible mechanism having an internal cylinder and external one. A compression stress is generated in the internal cylinder back face by the load acting on the cutter front face. This calculation was carried out on the assumption that the load acting on the front face is the earth pressure at rest calculated from the earth covering load

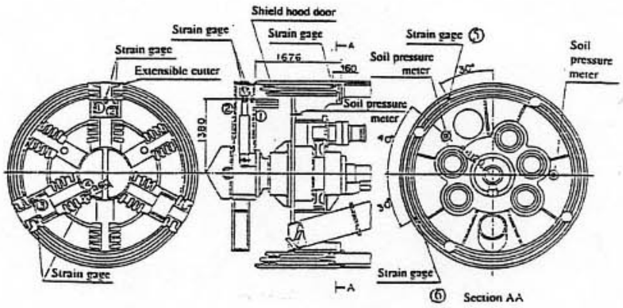

Fig. 9 Fitting Arrangement of Soil Pressure Meters and Strain Gages

Table 1 Stress Data at Various Sections of MSD Shield Machine

Measure-ment sectio \ Calculated & Measured values	Calculated stress (N/mm^2)	Calculated strain $\times 10^{-6}$	Measured strain $\times 10^{-6}$
(1) Cutter spoke internal cylinder, back face	–7.8	–39	–20 ~ –30
(2) (3) Cutter spoke internal cylinder, side face	17.0 ~ 51.0	83 ~ 243	0 ~ 120
(4) Cutter spoke root, side face	–30.1	–146	–140 ~ 0
(5) Main body hood section, top	–4.2	–20	–10 ~ –5
(6) Main body hood section, left side	–4.7	–24	–15 ~ –5

and that the internal cylinder is a cantilever.

(2) & (3) Cutter spoke internal cylinder (side faces stress)

A stress is generated in each internal cylinder side face by the cutter torque. Calculation was carried out for both cases where the actual excavation torque was divided equally on three extensible cutters and acted on the cutter ends as concentrated loads and where the torque was supported by one cutter only.

(4) Cutter espoke external cylinder (side face stress)

A stress is generated in the external cylinder side face by the cutter torque. Calculation was carried out by means of the displacement method with the cutter spoke roots fixed and with concentrated loads acting on the cutter ends.

(5) & (6) Main body hood section of shield

The main body hood section of the MSD method shield machine is of the overhung construction longer than that of the conventional machine in order to fit the docking mechanism. Therefore, it is considered that large stresses are generated around the hood fixing section. The calculation model was assumed to be a three-dimensional cylinder of a limited length having its fixed end at the highly-rigid bulkhead. The maximum analyzed stress is the axial compressive one of 24.5 N/mm^2, but calculated values at the positions fitted with strain gages (5),(6) are as shown in Table 1.

As seen in this table the calculated values agree very well with the measured ones, and so appropriateness of this design technique for the important sections of the MSD method shield machine is demonstrated.

In addition, the operations of the extensible cutters during and just after excavation and penetration of the penetrating ring could be carried out smoothly, and so their high durability is also confirmed.

5. APPLICATION OF MSD METHOD

5-1. Construction of Penetration Accepting Room in Joint Section

From the water cut-off performance test results either of the following two types is considered applicable to the actual shield machine up to 0.8 MPa in water pressure for the construction of the penetration accepting room in the joint section. The higher pressure is considered to be coped with by combining the following two types, by increasing the contact pressure of the penetrating ring against the pressure receiving rubber or so on.

(1) Construction where the end of the penetrating steel ring contacts the pressure receiving rubber.

(2) Construction where grout is injected between the sealing brushes and into the penetration accepting room.

5-2. Excavation Equipment Capability

From the practical work excavation test results of the earth pressure balanced type machine, it is found satisfactory for the MSD method shield machine to have the normal machine equipment capability only from the viewpoint of both the cutter torque and shield jack force.

5-3. Application of Practical Machine

Fig. 10 shows the experimental slurry type MSD method shield machine of 3,470 mm in outside diameter. This is composed of the slurry type machine fitted with the penetrating ring and its counterpart, i.e. the accepting side main body, and was manufactured to demonstrate the overall docking method, referring to the results of the various experiments up to now. This succeeded in underground docking practically. Consequently, it is found no problem even for the slurry type shield machine to have the conventional machine equipment from the viewpoint of both the cutter torque and shield jack force. In addition both the position recognition performance of the machine during docking and the water cut-off performance of the joint section could be confirmed.

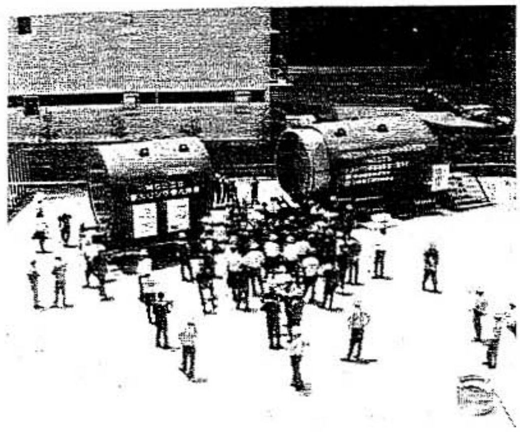

Fig. 10 Underground Docking Demonstration Test

6. CONCLUSION

Through the water cut-off performance test the fundamental data of the joint section sealing material that can cope with the water pressure of 0.8 MPa were obtained. In the experiments with the practical earth pressure balanced type and slurry type shield machines it was confirmed that the MSD method shield machines have the excavation performances equivalent to those of the conventional slurry or EPB shield machine satisfactorily, strengths of various sections peculiar to the MSD method shield machine were checked to confirm their durability, and also the docking operation, the water cut-off performance of the practical joint sections, etc. were confirmed totally during practical docking. (Fig. 10).

Thanks to the above development results, the MSD method is adopted to the underground docking work being carried out in Tokyo. The MSD method shield machine for this work was manufactured and is now used in excavation. Docking will be completed in 1992. From now on we will increase our experience on this method and simultaneously expand the application range of this method.

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Development of shield machine for Mechanical Shield Docking method (Part 2)

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ABSTRACT: We have developed a new shield docking method called the Mechanical Shield Docking (MSD) method. In the MSD method shield machines have the special equipment for docking, and connect to each other mechanically.

During the development of the MSD method, the various fundamental tests finished up to now, and as overall demonstration of MSD method the field test of docking with the practical shield machines was carried out. As the results, the MSD method is adopted for underground docking in the sewerage work. This is the first-practical-use MSD method machine used in the practical use.

1. INTRODUCTION

Recently the depth and distance of the tunnel excavated by the shielding method tend to increase further in urban areas. This will mainly be caused by the situations that it becomes difficult year by year to secure land for constructing shield work shafts in urban areas, that the construction cost and time for the shaft become vast due to increased depth of shield works, and that for the undersea and under-river shields construction of their shafts themselves is nearly impossible.

For the purpose of solving above-mentioned problems, the shield work distance should be encreased and accordingly, underground docking of shield tunnels has been highlighted together with its shortening of construction periods.(1)

Conventionally, underground docking has been common with the application of the chemical grouting method or freezing method, which hardens the ground around the excavation face to prevent ground collapse of the face top and spouting-out of pressurized ground water. The chemical grouting method has some problems relating to procurement of its ground plant and preservation of environments (ecology). The freezing method has such demerits to require not only a tremendously-long construction period for preparation, freezing and defreezing but also careful and sophisticated construction control for confirmation of the frozen area and prevention of ground settlement at the time of defreezing.

In order to replace such conventional methods, a new method called the Mechanical Shield Docking (MSD) method, which two shield machines opposing each other dock directly and mechanically without requiring any auxiliary work method, was developed through our joint research with Shimizu Corporation.(2)(3) In this stage, in order to demonstrate this method the experiment to dock practical shield machines underground was carried out. In addition the practical work of underground docking through the MSD method is being carried out. Now, their results and outlines will be reported.

2. GENERAL DESCRIPTION AND FEATURES

In the MSD method, two shield machines, one on the penetrating side and the other on the accepting side, move ahead underground, excavating soil toward each other, and when they meet face to face, their cutter head diameters are reduced. The steel ring built in the shield machine on the penetrating side penetrates into the accepting room of the shield machine on the accepting side so that the two machines dock each other mechanically. This docking section stands against the surrounding earth and water pressures and prevents water from leaking into the machines. The sequence of the docking method is shown in Fig. 1.[4]

(1) The two shield machines which have been moving forward from both sides while excavating stop shortly before the contact of their cutters. Their cutter head diameters are reduced in the extensible spoke mode while a mud water or slurry pressure is applied from inside the shield machines to the excavation face, and shield machines are driven ahead while the cutter heads are pulled to slide into the chambers.

(2) The penetrating steel ring built in the hood section of the shield machine on the penetrating side is inserted with a pressure into the accepting room of the shield machine on the accepting side. Then, the penetrating ring joins with the pressure receiving rubber ring (in the penetration accepting room), holding the pre-determined contact pressure.

(3) The shield machines are disassembled and removed except for the docking section, and the secondary concrete lining is placed.

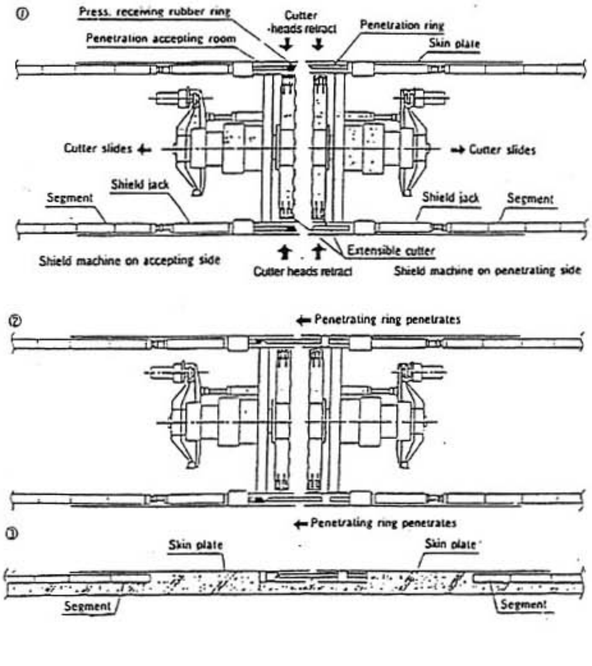

Fig. 1 Process of MSD shield machine docking
After the cutter head diameter has been reduced, the penetration ring is inserted into the accepting room to accomplish the docking.

3. OBJECTIVES AND HISTORY OF DEVELOPMENT

The objectives to develop the MSD method are as follows:

(1) This method could achieve the easy control of the underground docking and shorten the construction period without disturbing the natural ground around the shield machines.

(2) This method has the high water cut-off performance at the joint section.

(3) The MSD shield machine

(i) is applicable to both shield methods of the slurry type and earth pressure balanced type , and

(ii) has the performances and operability similar to those of the conventional machines.

From the view point of above development objectives, the technical problems to be solved were considered and various fundamental tests were carried out since 1986 (Having been reported by "Development of Shield Machine for MSD Method (Part 1)". On the basis of these results, as a conclusion of this development, the slurry type MSD method shield machine of 3,470 mm in excavation diameter (for the demonstration test) was designed, manufactured and put into the overall practical machine demonstration tests including the excavation and docking tests.

These overall development results have become the motive power to make the MSD method adopted to the practical work.

4. DOCKING DEMONSTRATION TEST

As overall demonstration of the MSD method, the field test of docking with the practical MSD shield machines was carried out. The slurry type MSD method shield machine excavated about 40 m and docked with a receiving equipment installed previously in the arrival shaft. During this excavation and docking work, all test items were confirmed and their data were acquired.[4]

Fig. 2 shows the concept of the demonstration test. Fig. 3 is the outside views of the shield machine and receiving equipment. Fig. 4 shows the soil condition and Fig.5 shows the test flow chart.

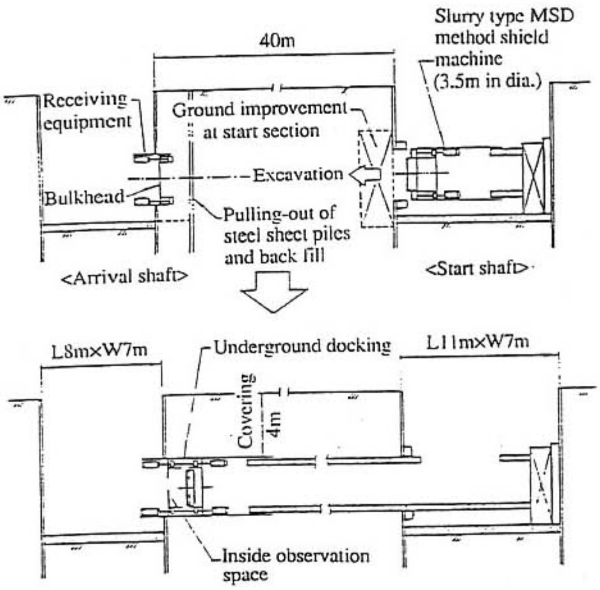

Fig. 2 Concept of demonstration test

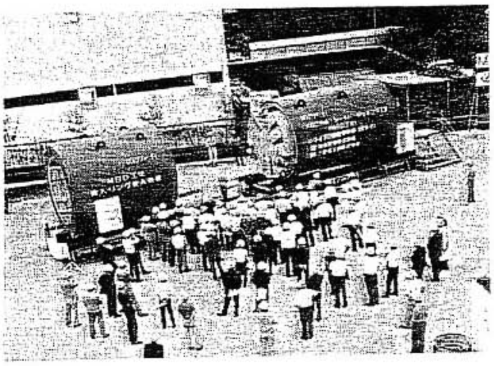

Fig. 3 Outside views of shield machine and receiving equipment

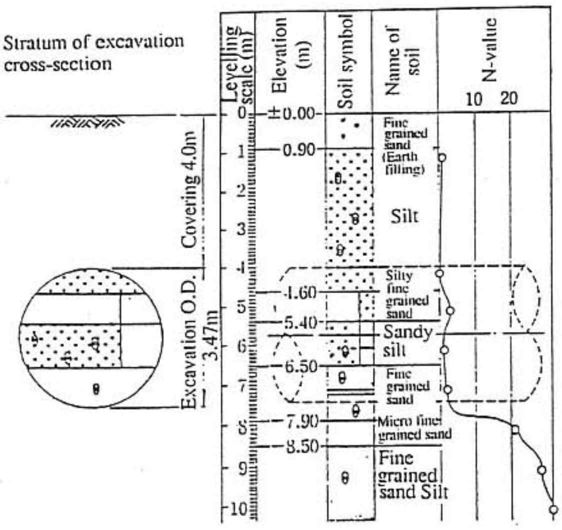

Fig. 4 Soil condition

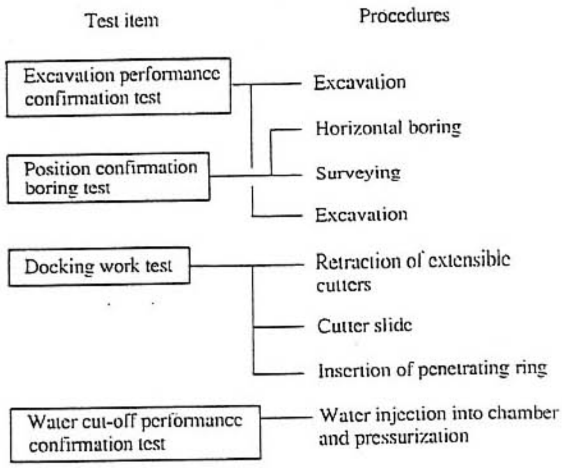

Fig. 5 Test flow chart

4-1. Outline of Work

Work place: Ichikawa City, Chiba Prefecture
Work condition: Sandy silt, silty fine sand, fine sand and silt
N-value = 1 to 2
Excavation length: 40 m
Cover length: 4.0 m
Shield diameter: 3,470 mm
Shield type: Slurry type

4-2. Test Results

a) Excavation Performance (Slurry Type)

Based upon the actual excavation data, amount of forces used such as the cutter torque and shield jack force is 50% or less of that of their respective designed capacities. Therefore, it is confirmed that the slurry type MSD shield machine has also a sufficient margin with the conventional machine equipment.

In addition, in the test the start and arrival points were biased by 150 mm previously in the horizontal direction and excavation was carried out, conducting survey in the tunnel. However, the track was corrected similarly to the case of the conventional machine and at the docking point, such good accuracies could be attained as 7 mm horizontally and 20 mm vertically.

b) Position Confirmation Boring Test

The system that monitors directly the shield machines during docking to confirm the accuracies was demonstrated.

Fig. 6 shows the procedures of the operation necessary for this survey. For horizontal boring the boring method called the earth arrow method was adopted and carried out at the point about 17 m before the docking point. The results show that the boring accuracy was ± 2 mm and workability was good for both the boring equipment and receiving one. However, the safety factor for casing pulling-out strength was found out to be low and it should be studied fully before adopting the earth arrow method.

c) Water Cut-off Performance Confirmation Test

After the machine docking work (about 10 hours) was completed, the water cut-off performance between the penetrating ring and pressure receiving rubber was confirmed.

In the test the chamber of the shield machine was supplied with water and pressurized to 0.59 MPa. Then, the water supplement rate to keep this pressure was measured as the water leakage rate. Fig. 7 shows the relation between the time and water supplement rate at the water pressure of 0.59 MPa.

According to this diagram the water leakage rate is 0.08ℓ/min only even under such high water pressure as 0.59 MPa, and it is confirmed that there is no problem in welding the docking section to make it the permanent water cut-off construction.

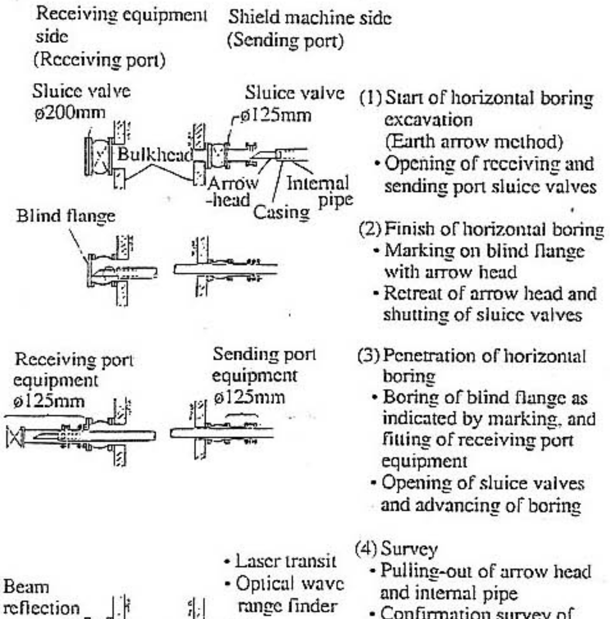

Fig. 6 Procedures for position confirmation boring

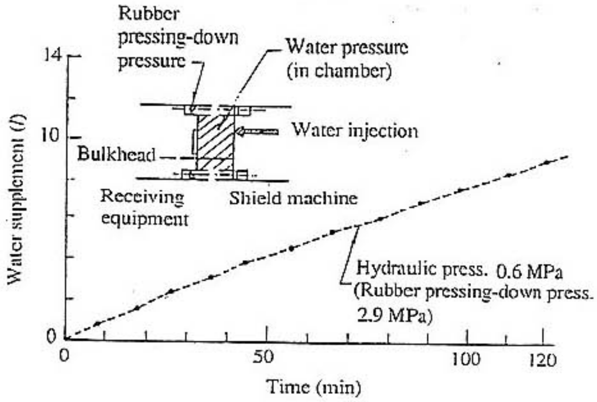

Fig. 7 Relation between time and water supplement rate (water press. 0.59 MPa)

5. MSD METHOD DOCKING WORK

Due to the results of the various fundamental and demonsrative tests finished up to now, the MSD method is considered to be suitable for underground docking in the water works of Tokyo Metropolis. This is the first practical-use MSD method machine used in the practical use.

As shown in the aerial photograph Fig. 8 this

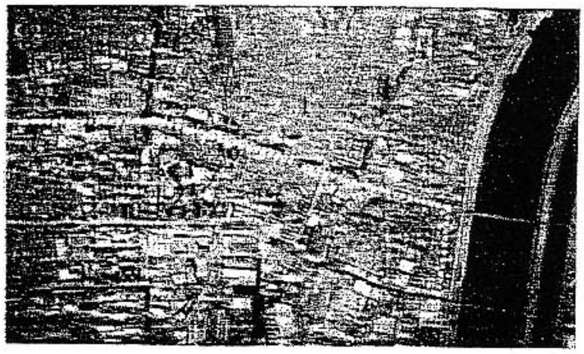

Fig. 8 Site location

shielding work is excavation under roads where there is very much traffic and high buildings stand in rows at both sides. Moreover, at the docking point many electric power cable tunnels, gas pipes, telephone cables, sewere pipes, aqueducts, etc. are buried just above the intended tunnel. It is almost impossible to construct the shaft at the arrival point. Thus, underground docking has been planned. However, the conventional underground docking method requires works of auxiliary work method from the road. This not only gives obstacles to traffic but also requires shifting or protection of the buried cables, pipes, etc. and may damage inhabitants in the surrounding area with vibrations and noises. The MSD method has been adopted for this docking, since this is the optimum method to solve all these problems and is judged to have such merits that the work period may be shortened and so on.

In this case the shield machine on the penetrating side with the penetrating ring is the earth pressure balanced type shield and the machine on the accepting side having the pressure receiving rubber ring is of the slurry shield.

Figs. 9 and 10 show the outside views of the shield machines on the accepting side and penetrating side, respectively.

5-1. Outline of Work

Work place:	Tokyo Metropolis	
Work condition:	Cohesive soil, N-value = 0 to 5	
Shield type:	Earth pressure balanced type	(penetrating side)
	Slurry type	(accepting side)
Excavation length:	1747 m	(penetrating side)
	1844 m	(accepting side)
Cover depth:	30 m	(docking section)
Radius of curvature:	25 m	(penetrating side)
	40 m	(accepting side)
Shield diameter:	3,430 mm	

5-2. Shield Machine on Penetrating Side

This shield machine having the penetrating ring is the earth pressure balanced type. The cutter spoke has the extensible mechanism and cutter head can slide together with the cutter driving section. Fig. 11 is the outside view of this machine with the penetrating ring extended. This machine started the excavation in November, 1991 and will reach the docking point in 1992.

5-3. Shield Machine on Accepting Side

This shield machine having the pressure receiving rubber ring is the slurry type with circumferential ring on the cutter head. This is effective in preventing natural excavating face from collapsing, and preventing the circumferential ends of the cutter spokes from wearing off during gravel ground excavation or long-distance excavation. The circumferential ring is designed to be connected to

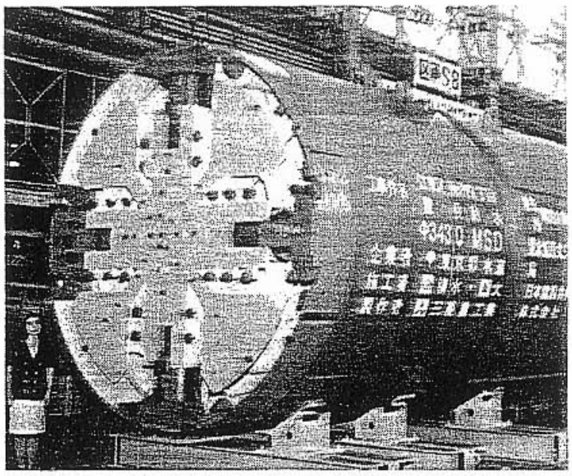

Fig. 9 Accepting side MSD shield machine

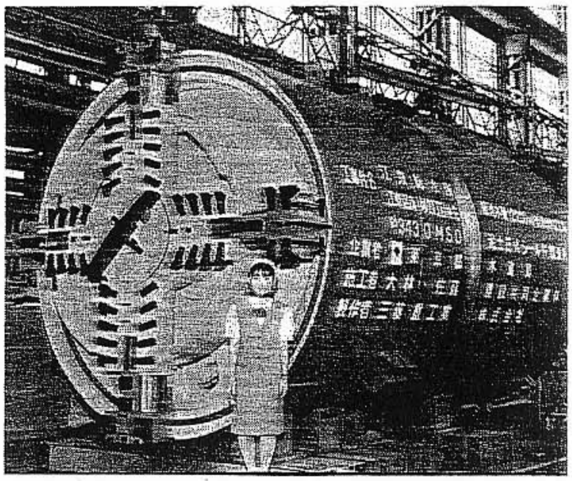

Fig. 10 Penetrat ing side machine
(Obayashi Corporation JV)

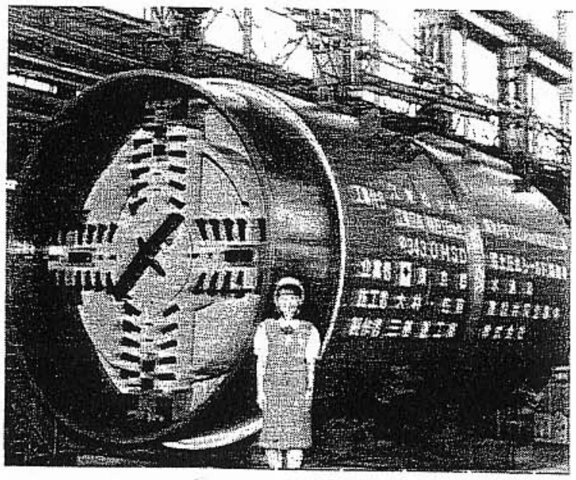

Fig. 11 Condition wherein the penetrating ring extended

the cutter spokes securely during normal excavation and the cutter spokes are designed so that they can be shortened easily before docking. The connecting mechanism of the circumferential ring and cutter spokes is the pin connection type (see Fig. 12) and before shortening the spokes these connecting pins are to be cut with a core cutter from inside the shield machine.

5-3-1. Measurement Items

For this shield machine, the following measurements were carried out.[5]

(1) Strain Measurement of Circumferential Ring

The circumferential ring of this machine is pin-connected to and supported by four extensible spokes and large stresses are generated in them during excavation, especially curve excavation. Therefore, strain gages are fitted on the circumferential ring in the circumferential and axial directions for continuous measurement during excavation.

(2) Stability of Excavation Face

Since the openings in the circumferential section of the cutters are larger than those of the ordinary slurry type shield machine, the penetrating type investigation device was fitted to the top position of the machine. This could measure the collapse size at the excavation face top to check the possibility of collapse due to excessive soil excavation.

(3) Wear Detection of Pressure Receiving Rubber Ring

This shield machine is the one on the accepting side and fitted with the pressure receiving

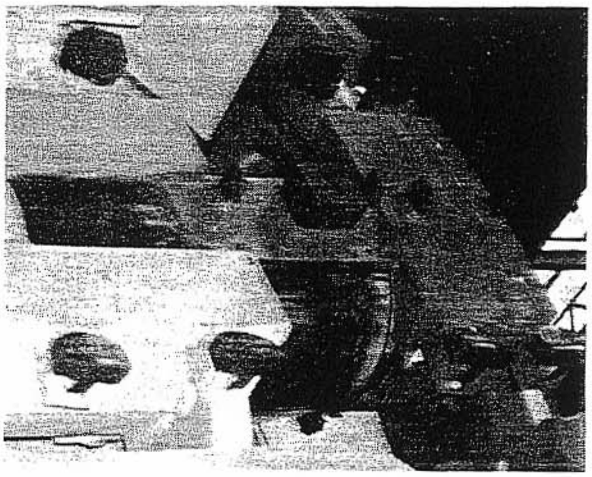

Fig. 12 Pin connection type

rubber ring in its chamber. Therefore, wear of the rubber ring during excavation should be detected. There are three kinds of the detecting dimensions, i.e. 3, 6 and 9 mm. Electrode type sensors were used.

The measurement instruments mentioned above are shown in Fig. 13.

5-3-2. Measurement Results

(1) Strain Measurement of Circumferential Ring

The results of the strain (stress) measurement is for every excavation distance and division are shown in Table 1. In the table, the measured values scatter for both the circumferential and axial stresses in the circumferential ring. However, in the circumferential direction higher stresses appeared during normal ground excavation than those during curve excavation of modified ground. This is due to difference in load conditions on the cutter spokes and circumferential ring between excavation of a relatively self-supporting natural ground and soft one. Besides, in the axial direction, it is considered that variations of the axial force (difference between the shield jack force and face water pressure) may have any influence. However, the stresses in both circumferential and axial directions are less than 10% of the allowable stress of the material used (ss 400, 137 N/mm^2). Therefore, this circumferential ring of the pin connection type could not have any structural problems in practical excavation.

(2) Stability in Excavation Face

The upper part of excavation face collapse size is about 4.4 mm on an average during normal ground excavation. This is nearly equal to the size of the outbreak out side of the cutter, which is about 5 mm. Therefore, there is no ground collapse due to larger openings at the cutter circumferential

Table 1 Measurement Results

Excavation distance (Ring No.)	Circumferential ring		Excavation water press. (MPa)	Jack speed (mm/min)	Cutter torque (kN-m)	Total jack force (kN)	Axial force (Difference between shield jack force and face water pressure) (kN/m^2)	Remark
	Circumferential stress (N/mm^2)	Axial stress (N/mm^2)						
12	−1.0	−1.0	0.02	7.2	1.24	11.8	4.05	Column range Curve division
32	−1.0	−2.1	0.22	7.7	1.55	24.0	1.31	
83	0.0	1.0	0.25	12.6	1.21	39.5	6.60	Chemical grouting range Curve division
87	0.0	−1.6	0.26	23.0	1.36	41.1	6.86	
110	−1.6	1.6	0.25	22.9	1.38	49.8	10.75	
130	−4.6	3.1	0.24	23.5	1.33	61.5	15.68	Normal natural ground Straight division
174	−10.8	—	0.18	23.8	1.37	41.3	9.84	
189	−9.3	—	0.18	25.3	1.38	44.5	11.03	

* Figures are averages of values measured in ring.

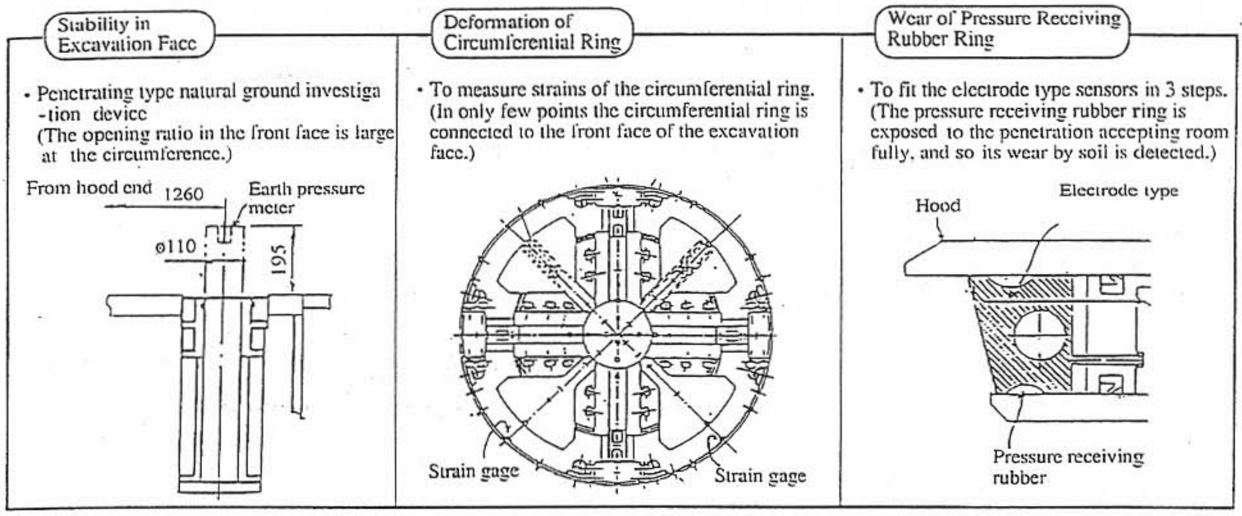

Fig. 13 Measurement instruments for shield machine on accepting side

section than those of the conventional slurry type shield machine. Consequently, smooth excavation may be continued.

(3) Wear Detection of Pressure Receiving Rubber Ring

After excavation of 230 m, the electrode sensors showed no reaction. Therefore, no wear is occurred on the pressure receiving rubber ring.

This shield machine started excavation in 1990. Both observed cutter torque and shield jack force are similar to those of the conventional machine. Even the sharp curve of 40 m R was also excavated without any error from the pre-designed course and the steering performance of this machine is similar to that of the conventional one. This machine is now excavating smoothly, and is to reach the docking points in 1992.

6. CONCLUSION

By means of the demonstration with the practical shield machine, it is confirmed that the MSD method machine has the excavation performances similar to those of the conventional one and does not have any problems. Docking work and water cut-off performance and also found to be satisfactory.

Due to the above-mentioned results, the MSD method is adopted to the underground docking work being carried out in Tokyo. The MSD method shield machine for this work was manufactured and is currently used in excavation. From now on, more experiences upon the MSD method will be occumulated and its applicable area will be expanded further.

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