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The development of "Gyro Runner", a totally unmanned shield guiding system

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Abstract

This paper reports on the development of 'Gyro Runner', a totally unmanned shield guiding system, consisting of the automatic survey system and the automatic shield guiding system.

More than 90% of current shield tunnels are small-bore and of curved geometry, where a gyrocompass mounted in the machine have been frequently used. However, the gyrocompass cannot detect the potential side slip of the shield machine, and the accumulated positional error can only be adjusted by a conventional tunnel survey. A system that minimizes such survey work has been developed.

The new survey method comprises an autotracking total station, a laser gyro and an image processor, and performs accurate shield position/posture detection by referring to the survey points at every measurement cycle.

The shield guiding system, on the other hand, selects the optimum jack pattern and directional control procedure that conducts the shield machine on the planned line.

On site, good accuracy and labor saving effect have been verified.

1. Introduction

Many developments aiming at total shield work automation have been carried out by contractor firms. Among these, cases of position/posture survey technology development have been often reported. Most of these, however, are for large cross section shields. Small-bore, and especially curved geometry tunnels have little internal work space , reason why automatic survey in such cases have been considered difficult to perform.

Aoki Corp. has developed the 'Gyro Runner', a guiding system for small-bore, curved geometry shield tunnels, capable of accurate positional detection and guiding. The system has already been implemented on site, and shown satisfactory results.

2. Conventional automatic survey methods

Automatic survey methods in use today can mainly be classified in three types: (1)the optical method(fig.1), which uses light wave survey instruments ; (2)the gyrocompass method(fig.2); and (3)the optical/gyro method(fig. 3),which is the combination of both. To each method, some problems can be pointed out:

(1)Optical -light path necessary
-influence of segment shift
-constant re-establishment of survey points required

(2)Gyrocompass -machine side slip error
-cumulative error
-check survey (once or twice a day) required

Yet, (3)gyro/optical method, which combines the advantages of both, meets the same problems in a small tunnel environment.

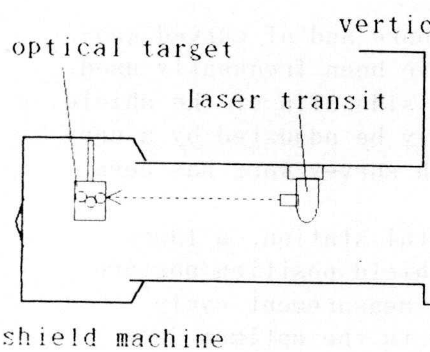

Figure 1. The optical method

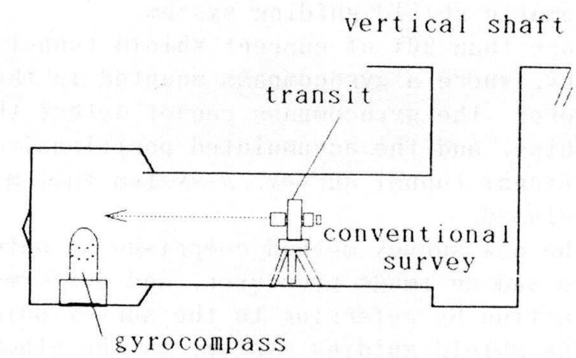

Figure 2. The gyro compass method

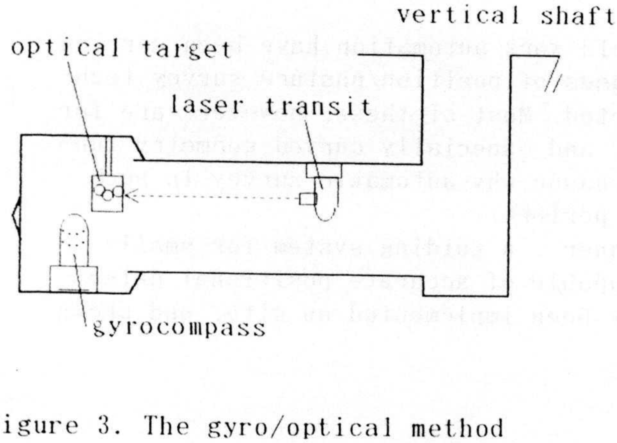

Figure 3. The gyro/optical method

3. Development directions on the new survey method

An accurate shield survey is possible if the machine can be collimated by a survey instrument placed on a steady reference point, usually located far back in the tunnel. In small tunnels, however, backup trains obstruct the necessary light path.

To overcome this, a gyro sensor, instead of being placed on the shield machine, was put to run to and fro between the both ends of the backup train, in a way that survey can be performed even when light path's not available. An autotracking total station, placed on the backmost carriage of the backup train, was used to detect the posture and the position of the back end of the route followed by the running gyro. At the backup train's front end, an image processor was placed in order to follow the movement of the shield.

By adopting this method, the labor required for re-establishing reference survey points can be minimized, and also survey errors due to segment shift can be avoided.

4. The Automatic Survey System

4.1 OVERALL DESCRIPTION

The above described directions were materialized in the form of three subsystems, distributed in the tunnel as shown in figure 4.

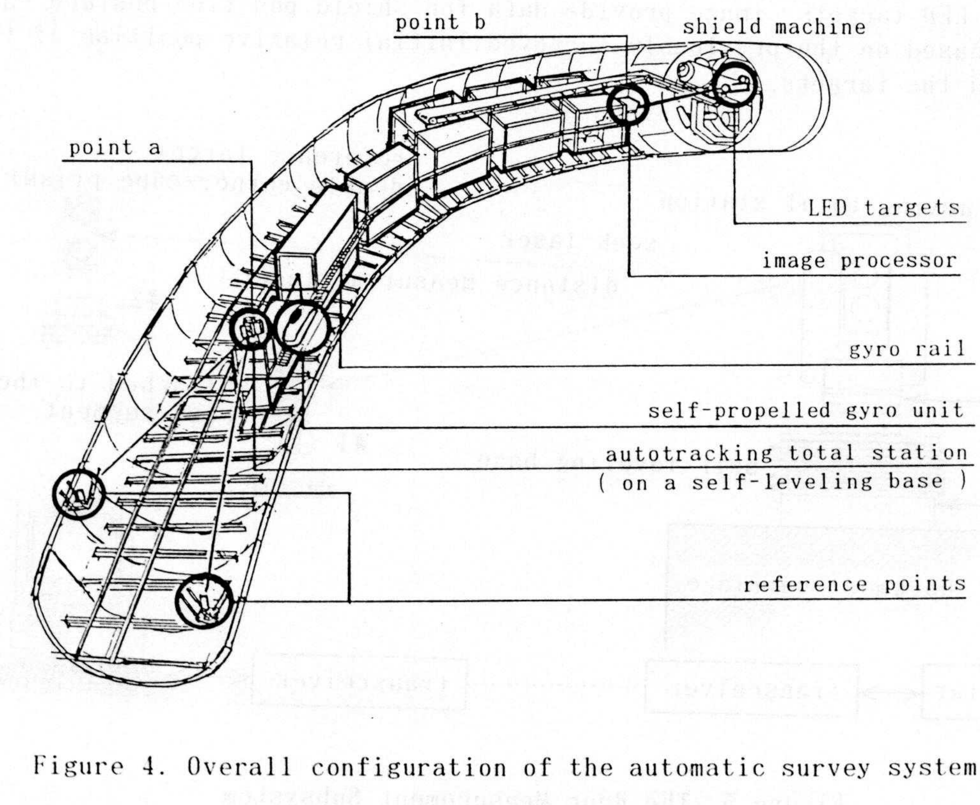

Figure 4. Overall configuration of the automatic survey system

4.2 MEASUREMENT METHODS AND SYSTEM CONFIGURATION

(1) Rear Measurement Subsystem

Figure 5 shows the configuration of this subsystem.

The light wave total station at the backmost carriage of the backup train can automatically seek for the target prisms. This instrument was installed on a self leveling table, which keeps the base at level posture with an accuracy of 10 (ten) seconds.

The measuring point 'a''s position and posture are calculated from the direction and the azimuth to each of the two prisms. The adopted mathematical methods were the Reduction and the Weisbach Triangle methods.

(2) The Gyro Car Subsystem

The Gyro Car Subsystem's configuration can be seen in figure 6.

A self-propelled car bearing a Laser Gyro travels between the two ends of the backup train, on a rail placed throughout its extension. While running, the subsystem continuously measures distance and azimuth, from which the route line, and thus the relative position/posture of the end points 'a' and 'b', are calculated.

(3) The Shield Detection Subsystem

The configuration of the Shield Detection Subsystem is shown in figure 7.

Two circle-arranged LED targets are fixed to the previously known points in the shield machine. They are detected by an image processor with its two cameras placed at the front end of the backup train. The centroid coordinates of the LED targets' image provide data for shield position/posture calculation, based on the previously surveyed initial relative position of the cameras and the targets.

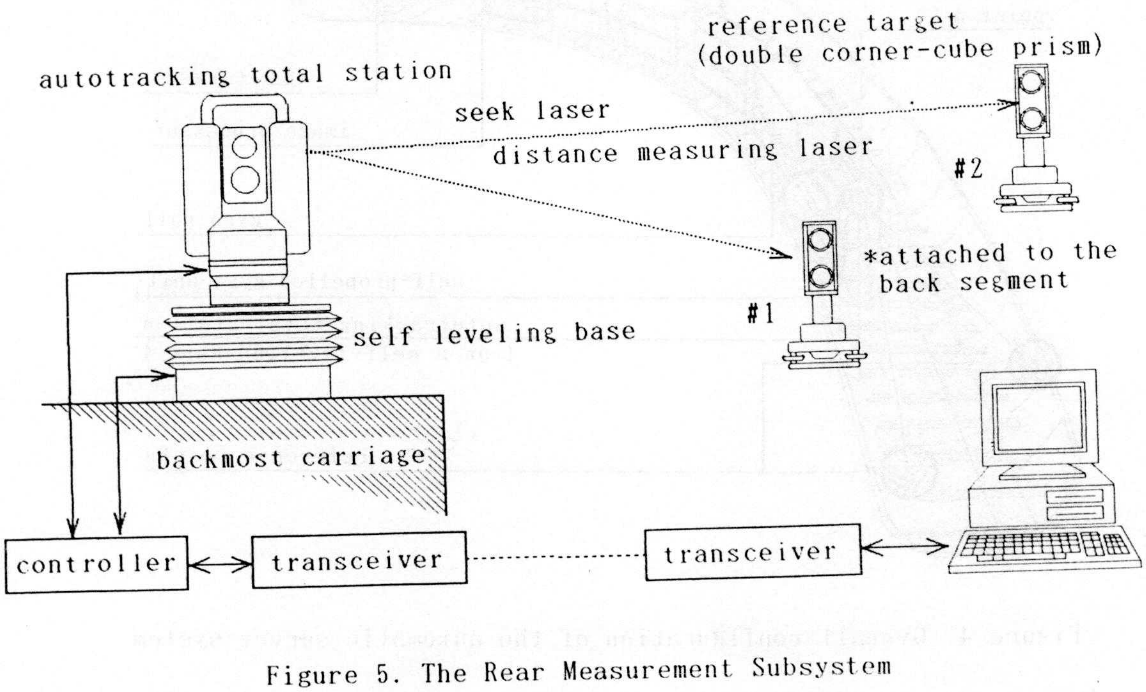

Figure 5. The Rear Measurement Subsystem

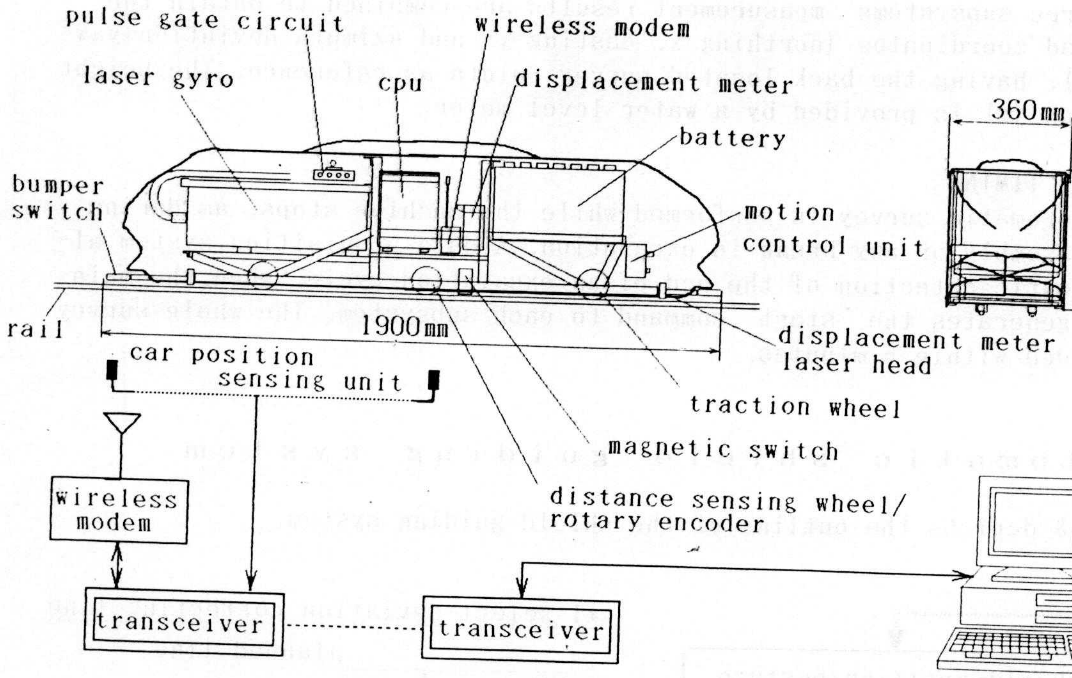

Figure 6. The Gyro Car Subsystem

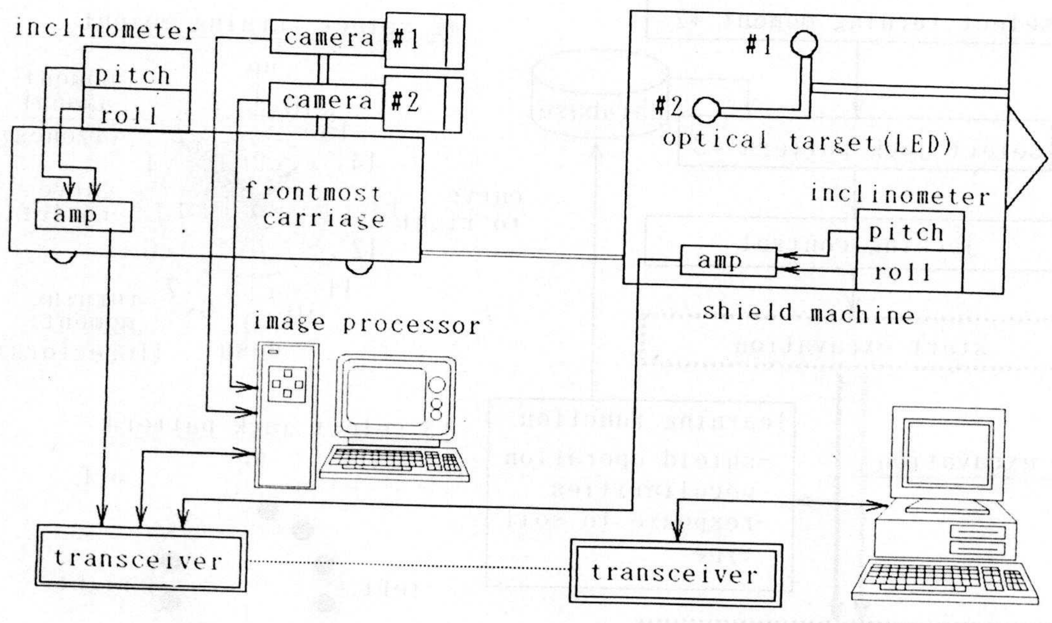

Figure 7. The Shield Detection Subsystem

The three subsystems' measurement results are combined to obtain the shield head coordinates (northing x, easting y) and azimuth deviation (yawing angle), having the back located survey points as reference. The height information (z) is provided by a water level meter.

4.3 SURVEY TIMING

The automatic survey is performed while the machine stops, as during segment assembly or any break in excavation. A data acquisition system allows automatic detection of the end of an excavation cycle, when the main computer generates the "start" command to each subsystem. The whole survey is concluded within 5 minutes.

5. Automatic shield guiding system

Figure 8 depicts the outline of the shield guiding system.

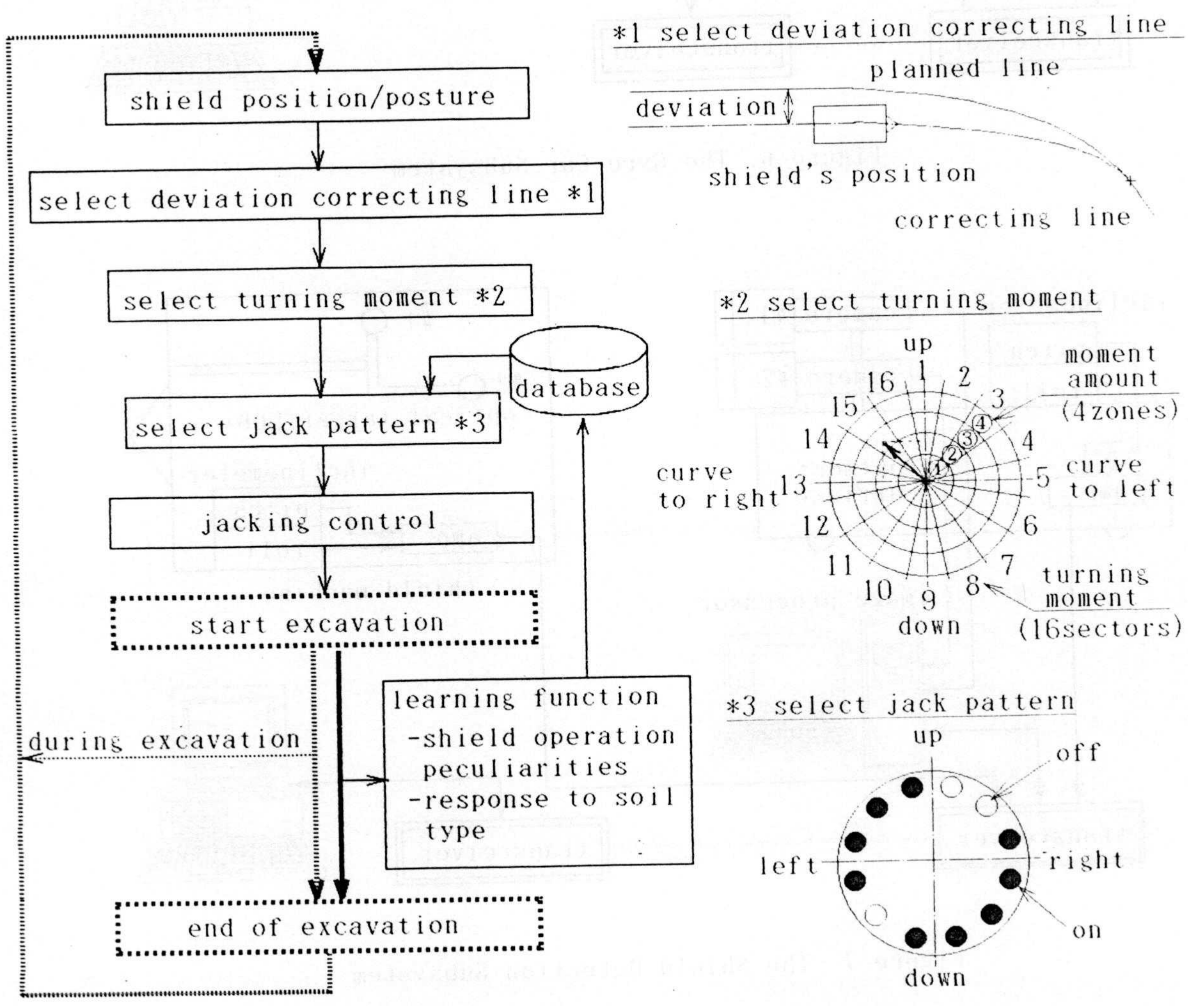

Figure 8. Jack pattern selection and jacking cotrol flow

In conducting the shield machine on the planned course, adequate jack pattern and jack control procedure must be selected, taking into consideration factors like terrain condition and machine operating peculiarities. Currently, operators make such decisions. This system, by using its learning function, automatically selects the optimum jack pattern and the jack control procedure, with a decision level comparable to a human operator.

By the learning function, data as soil pressure(which influences machine behavior), the utilized jack pattern and the actual course taken by the shield machine, are accumulated in form of a database. With the required turning moment (calculated from the current shield machine deviation from the planned course), and environment condition data as soil pressure, a similar situation is sought in the database, and by this means a suitable jack operation procudure is chosen. From the alternation of the jacking control and the evaluation of the resulting route, this system learns how to operate the shield machine in an optimum way.

6. Features of the system

(1)Suitability to small diameters (2 m) and sharp curves(30R)
(2)Survey without side slip effects, commonly seen in shield machines carrying a gyrocompass
(3)Survey free from cumulative error, due to constant reference to back points (in straight lines, unmanned operation is possible for more than a month)
(4)Automatic decision making similar to skilled operators, allow excavation according to the soil type and the machine peculiarities.
(5)The combination of the automatic survey and guiding systems makes unmanned shield work possible

7. Field results

The automatic survey system has been implemented on a real shield excavation site, and has shown precision suitable for excavation management (machine head position error within +/-20 mm). It was confirmed that unmanned survey for a period within a week and a month is possible.

The shield guiding system has also been introduced to site, where evaluation works have been carried out.

Figure 9 shows Gyro Runner in the shield site.

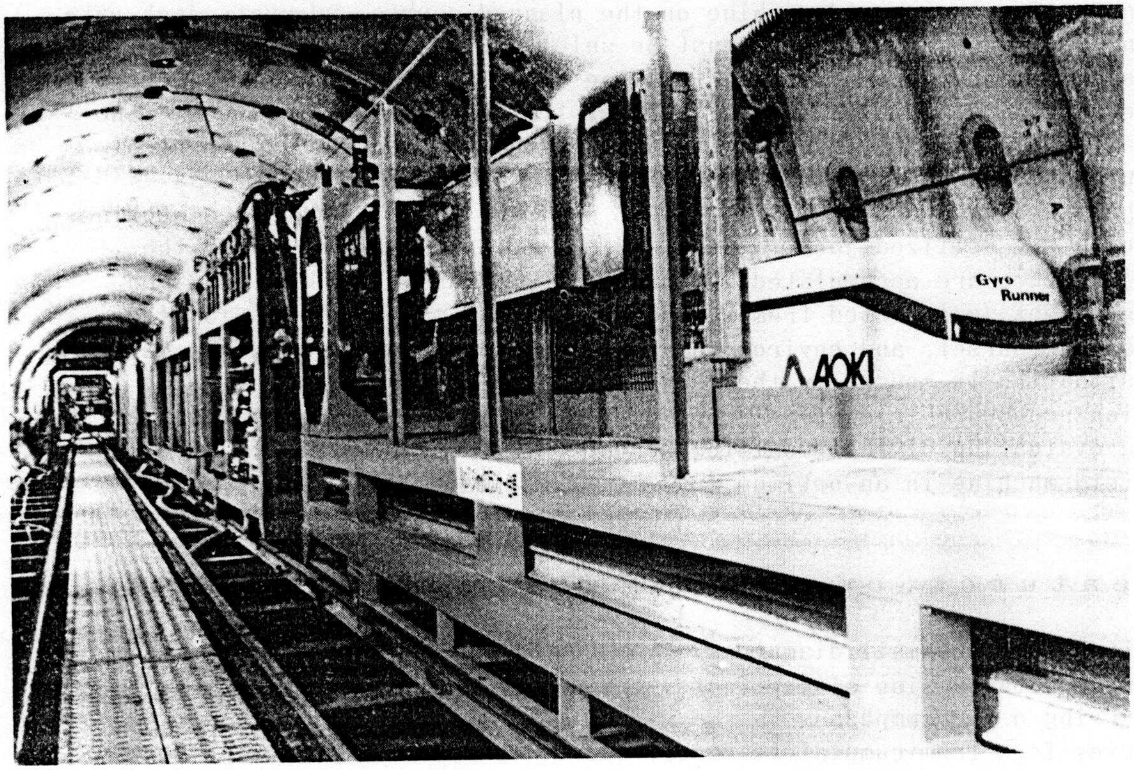

Figure 9. The Gyro Runner introduced to a shield site

8. Conclusion

To achieve a fully automatic shield work, element tasks as excavation supervision, machine position supervision, directional control, segment assembly and material conveyance, require automation technology development. Among these, Gyro Runner represents accomplishments in directional control and automatic survey. Also, Aoki Corp. has already had practical results on excavation supervision, by developing the "Soil Volume-Controlled Shield Method", and the "Soil Pressure Shield Expert System". Our future efforts shall be focused on the remaining segment assembly and material conveyance automation.

We believe that the technology developed with Gyro Runner is applicable not only to shields but also to other kinds of construction works.