# Development of an Excavation Accuracy Control System for Diaphragm Walls

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## ABSTRACT

Recently, construction has been automated and labor-saving, and diaphragm walls have be come much deeper. In view of this, we have developed an accuracy control system for installing diaphragm walls, using a horizontal multi-axial rotating cutter for excavating. Using this system enables high-accuracy excavation easily. The system comprises two control functions, one for primary excavation, the other for excavation accuracy. Characteristic of the excavation accuracy control unit is that the wires for detecting cutter position are always kept vertical and automatically follow the cutter.

In this study, we confirmed, through static ability and field testing, that these devices are extremely useful for excavation control.

## 1. INTRODUCTION

The diaphragm wall construction system, which began in Europe in the middle of our century, has been used for more than 30 years and has enjoyed remarkable progress. Owing to its rigidity, water impermeability, minimal noise level, and minimal vibration, diaphragm walls have been employed as a mainstay in foundation work. Recently, they have been applied for general use in permanent underground structures.

Moreover, as underground structures have become more deeper, the need diaphragm walls having great depth and thickness has grown rapidly. And this has led to the introduction and further development of large-size excavators. The BC30 trench cutter, built by BAUER of Germany, features horizontal multi–axial rotating cutters, capable of quickly constructing diaphragm walls of great depth and thickness.

Owing to the high–level use and increasing depth of diaphragm walls, they must be made with great accuracy. MAEDA Corporation quickly planned to boost excavation accuracy after the MHL excavator, a bucket–type developed with MASAGO Industries, Ltd., and equipped with an unique clinometer (patent no. 1162152) which has excellent impact resistance, appeared on the market. In this manner, MAEDA has gained the technical ability to control excavation accuracy to a fine degree.

In this context, MAEDA has developed an excavation accuracy control system for use with the BC30 trench cutter which can detect absolute cutting position in real time and efficiently control excavation. This paper reports the introduction and testing of this system.

## 2. TRENCH CUTTER BC30

The BC30 trench cutter uses powerful hydraulic motors to spin its cutter drums, and excavates soil using teeth attached to the drums. The excavated soil, along with the slurry, is removed by a large–capacity, high–head mud pump via a suction box to ground level, where a separator removes the soil from the slurry.

Its major features:

① The ability to excavate all types of soil, from clay, sandy soil and gravel, to boulders and bedrock.

② Continuous excavation and soil removal provides for high–speed work.

③ Excellent vertical stability prpvides for highly accurate work.

The BC30 utilizes a computerized excavation control system. Table 1 shows the basic system. The excavation accuracy control system intends to perform still higher accuracy control grounded on the basic system.

**Table 1 Main specifications of the BC30**

| | | | |
|---|---|---|---|
| Excavating wall width | 2,800mm | Mud pump flow rate | 400m³/h |
| Excavating wall thickness | 640～2,400mm | Power requirement | 570PS |
| Excavating depth | 100m | Base machine | 150t crane |
| Cutter main body weight | 30～41ton | Boom length | 39m |
| Cutter drum torque | 7,140kg・m | Front operational radius | (78° )10.0m |
| Cutter drum rotational speed | 0～24rpm | Rear operational radius | 8.0m |

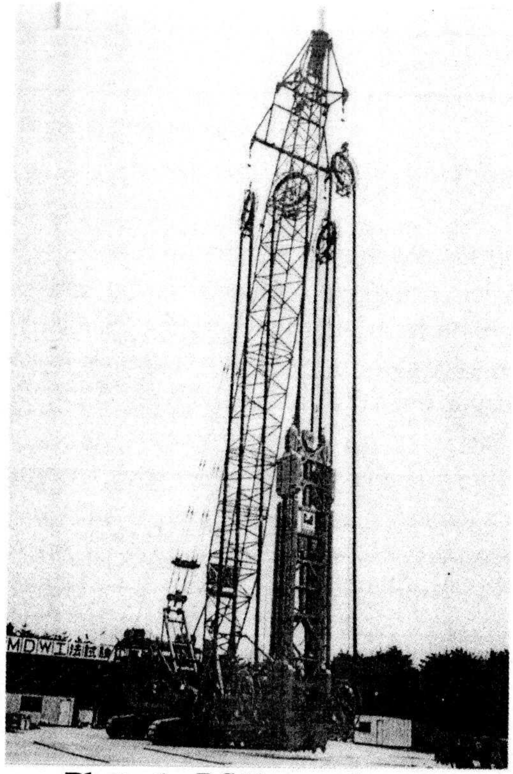


Photo 1 BC30 trench cutter

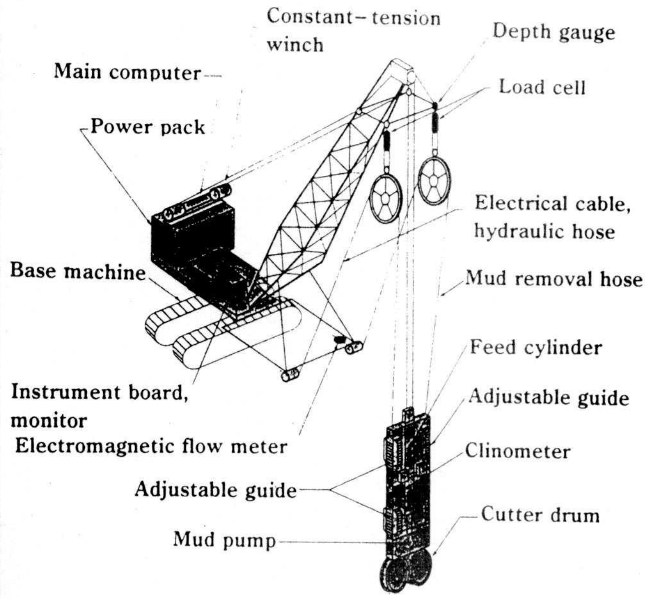



**Fig. 1 Basic excavation control system of the BC30**

## 3. EXCAVATION ACCURACY CONTROL SYSTEM

The excavation accuracy control system is designed to greatly enhance accuracy from start to finish of the job. Composition of the system is shown in Fig. 2.

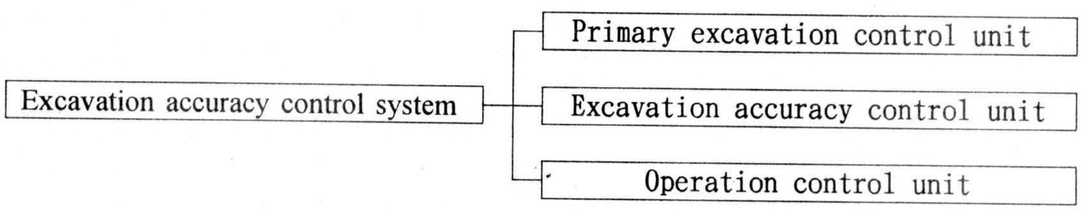



**Fig. 2 Composition of the excavation accuracy control system**

### 3.1 PRIMARY EXCAVATION CONTROL UNIT

Because of the influence it has later, primary excavation –until the cutter main body structure disappears in the guide wall– demands a high degree of accuracy. The primary excavation control unit of, shown Fig. 3, was developed specifically to meet this requirement. It comprises a primary excavation guide, a clinometer for the base machine boom, and a circle meter for the base machine.

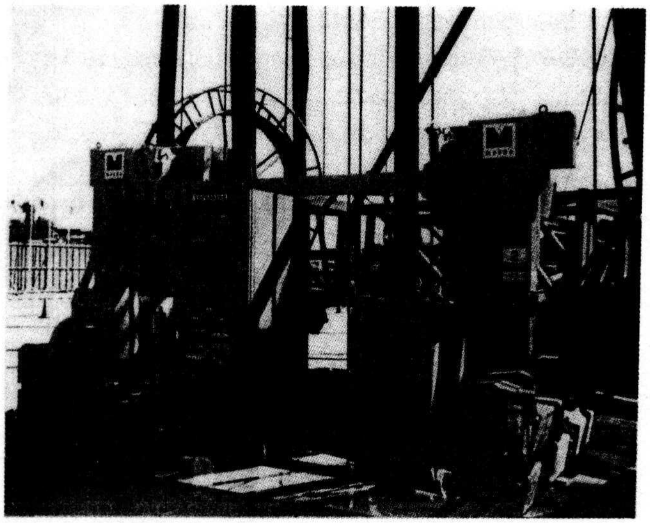


Photo 2 **Excavation accuracy control unit**

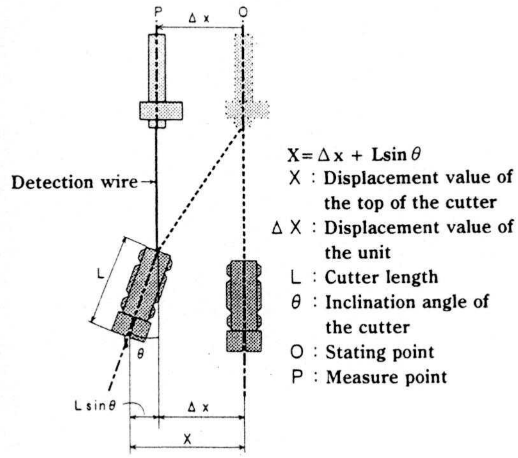



**Fig. 5 Measurement principle**

## (2) MEASUREMENT PRINCIPLE

The measurement principle (Fig. 5) has eliminated the need to find the cutter position, since its displacement value as measurement follows detection remains vertical at all times as the cutter moves. In addition, as mentioned, cutter inclination is measured by its clinometer (patent no. 1162152). Thus the absolute position of the end of the cutter is determined by adding its displacement and inclination angle.

## (3) COMPOSITION OF THE UNIT

The excavation accuracy control unit measures X and Y direction at two points on the top of the cutter simultaneously. It consists of several parts: two measurement pipes each equipped with a laser displacement sensor to monitor detection wire movement, two measure rods each equipped with a clinometer, two servomechanism displacement measuring devices which follow the cutter's movement, two constant-tension winch which assure that the detection wires remain taut, and a base which moves the unit fore and aft (Fig. 6). The base is made of sturdy steel pipe to enhance accuracy, and the entire unit is integral.

## 3.3 OPERATION CONTROL UNIT

The operation control unit consists of a computer and an instrument panel. The computer draws information from various sensors, and computes the data required for excavation. The computer's monitor displays the data in real time. In this manner, the BC30 is controlled via the instrument panel using this data. By looking

## 3.2 EXCAVATION ACCURACY CONTROL UNIT

### (1) OUTLINE

The excavation accuracy control unit, which plays the key role in this system, detects cutter position in real time following primary excavation. Most existing devices for determining cutter position do so using a thin detection wire linking the excavator and a detector equipped with various sensors. In the process, the detection wire has always leaned one way or another. In instances of great depth excavation, measurement results tend to produce errors owing to detection wire catenary curvature.

The excavation accuracy control unit developed by MAEDA enables shifting part of the fixed detection wire on the ground so that it remains vertical at all times. Characteristic of this device is that it automatically and directly follows cutter displacement value.

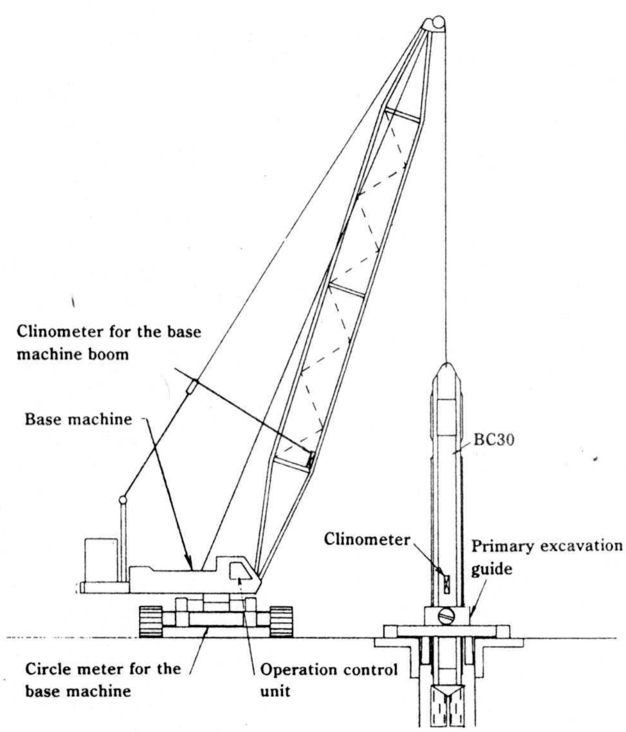



**Fig. 3 Primary excavation control unit**

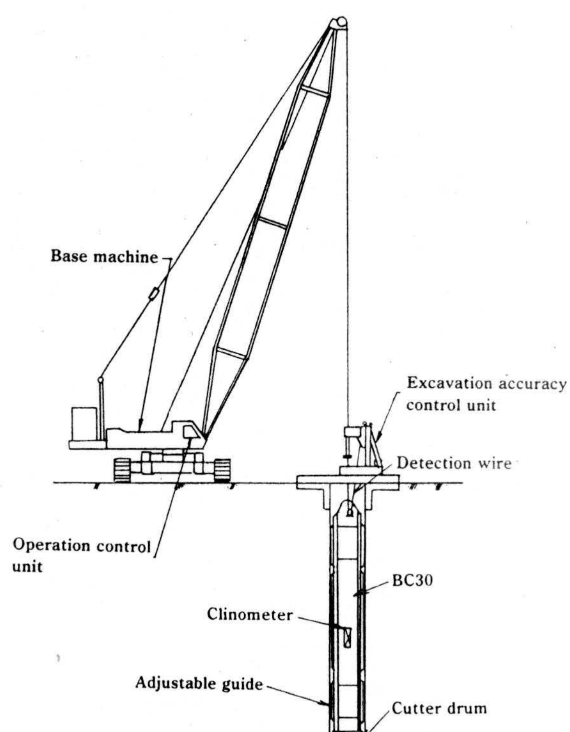
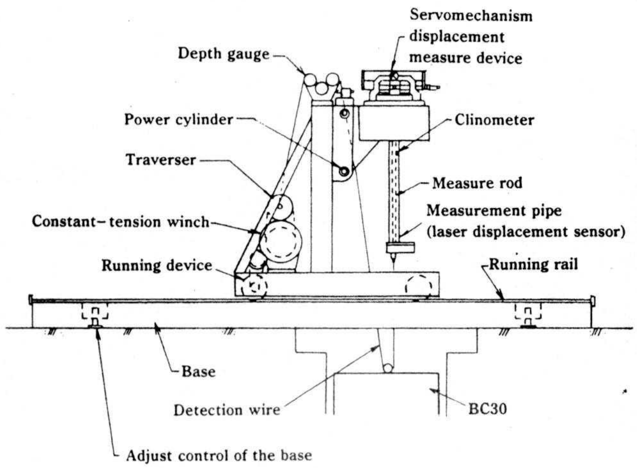



**Fig. 4 Excavation using the excavation accuracy control unit**

at the monitor display, the engineer operates the BC30 with adjustable guides so that cutter displacement always remains within the constant value. Photo 3shows the excavation accuracy control unit.



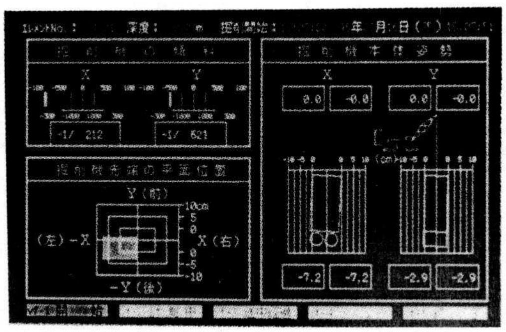



**Fig. 6 Composition of the excavation accuracy control unit**

**Photo 3 Excavation accuracy control monitor**

## 4. STATIC ABILITY TEST OF THE EXCAVATION ACCURACY CONTROL UNIT

### 4.1 OUTLINE OF THE TEST

After fabricating the excavation accuracy control unit, we conducted a basic functional test at the factory. Naturally, various types of machinery have specific functions; their components are influenced by depth of operation: detection wire response, performance of the servomechanism displacement measuring device, etc., thus requiring a more dependable measuring system. Taking such factors into account, we performed a static ability test to gain an accurate understanding of the influence of depth. The test was the reproduction and response variety, using a shield shaft.

### 4.2 TEST CONTENT AND RESULTS

### (1) REPRODUCTION TEST

The purpose of the reproduction test was to confirm whether the initial value of the laser displacement sensor and the clinometer varied as time passed. We drew the detection wire via an electric winch to the end of the shaft, then connected the measure rod using a sheave fixed jig. When causing the upper part of the wire to

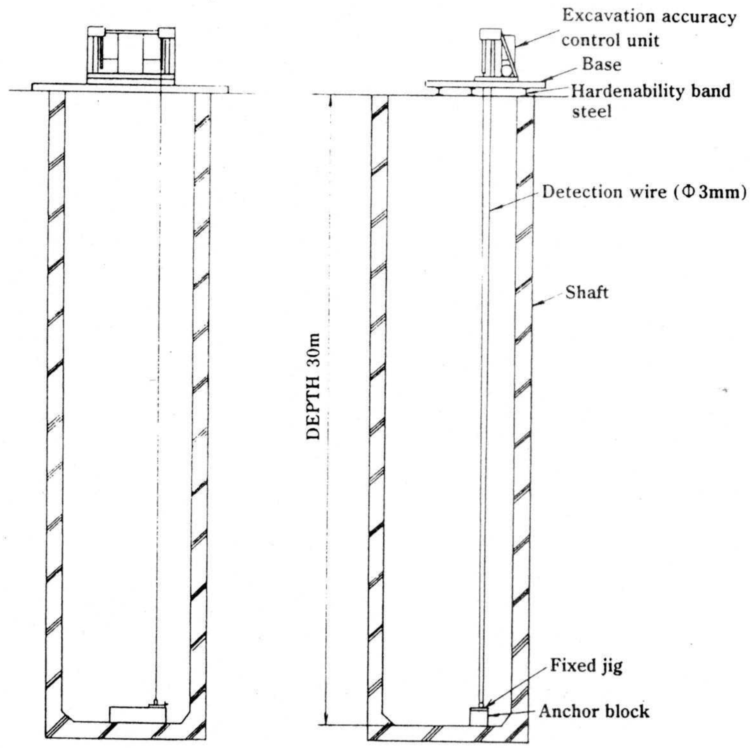



**Fig. 7 Outline of the test**

vibrate, we studied various values of the laser displacement sensor and clinometer.

The test was repeated five times. Because these values conformed with a high degree of accuracy, the responses of the laser displacement sensor and clinometer were pronounced satisfactory.

## (2) RESPONSE TEST

When the position of the lower part of the detection wire was varied according to the fixed jig, we took measurements. It confirmed that the value produced conformed to the displacement value of the detection wire.

Fig. 8 shows an example of the relation between the value produced and the displacement value. Since the relations agreed, the measurement was deemed accurate. This test was conducted 30 meters below ground. Because this method is not affected by the detection wire catenary curve, it is possible to ensure measurement accuracy at great depth.

## 5. FIELD TEST

### 5.1 OUTLINE

The field test was performed in Nagoya at the construction site of diaphragm walls using the BC30. Wall thickness was 80 centimeters, and their depth, 45 meters. The soil comprised sand and silt, and contained sandy gravel at a depth of about 35 meters.

Fig. 9 gives an outline of the ground. The primary excavation control unit was used for excavation to a depth of 16 meters, and the excavation accuracy control unit was applied beyond that depth.

To show that the excavation accuracy control unit has the desired function was given first priority in the test, and comparisons between detecting results of the system data and ultrasonic wall sensor were made at various depths.

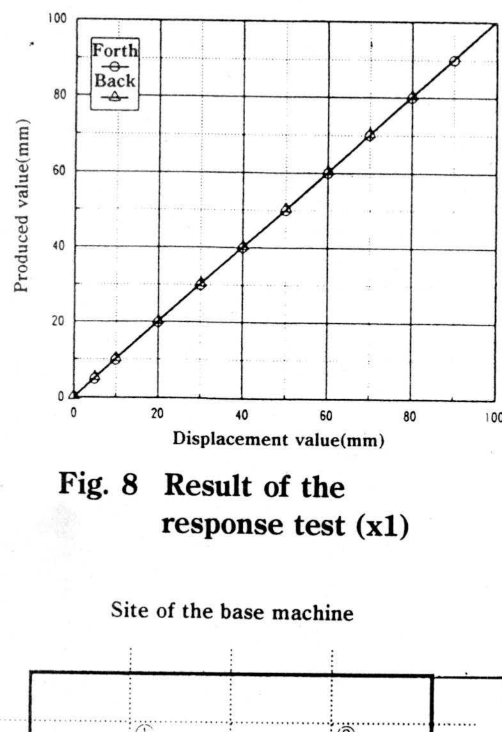



**Fig. 8 Result of the response test (x1)**

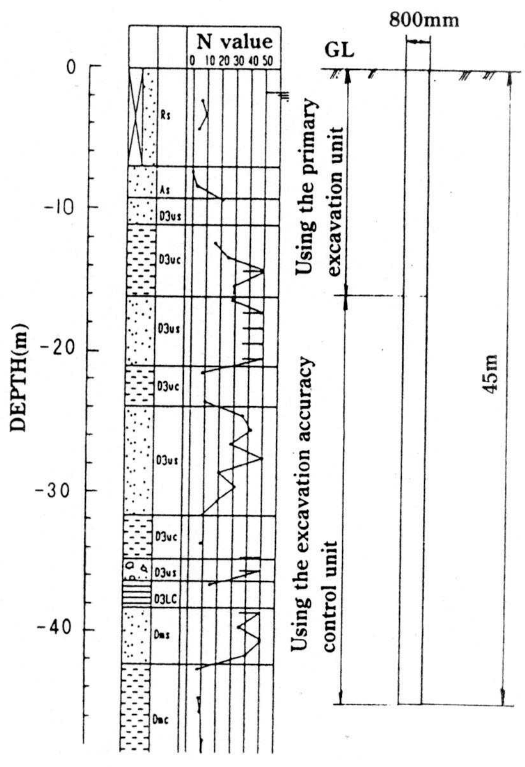



**Fig. 9 Outline of ground**

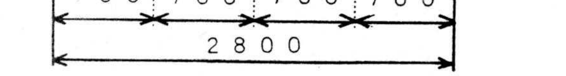



**Fig. 10 Position of ultrasonic trench detection**

## 5.2 CONTENT OF THE TEST

After excavation using the device was completed, we compared data between the ultrasonic trench sensor and the excavation accuracy control unit. Fig. 10 shows the position of the ultrasonic trench sensor, Fig. 11 presents its results, and Fig. 12 shows comparisons of the values at 0. 5 meters intervals below ground.

According to Fig. 11, overcut of the wall amounted to 0 to 6 centimeters, but mostly from 1 to 3 centimeters (average 2. 1 centimeters). The thickness of the BC 30 cutter drum was 800 millimeters. According to this gatt, it is regarded as wall clearance. Therefore, when comparing the two sets of values, it is considered that the cutter drum could move within the clearance.

We compared the two results (Fig. 12) and found that they closely conform. Thus we concluded that the unit's measurement function follows the movement of the cutter well with precision. The difference between the values is within plus and minus 1. 3 centimeters (95% probability). Judging from the above, the system's measuring accuracy can be described as excellent.

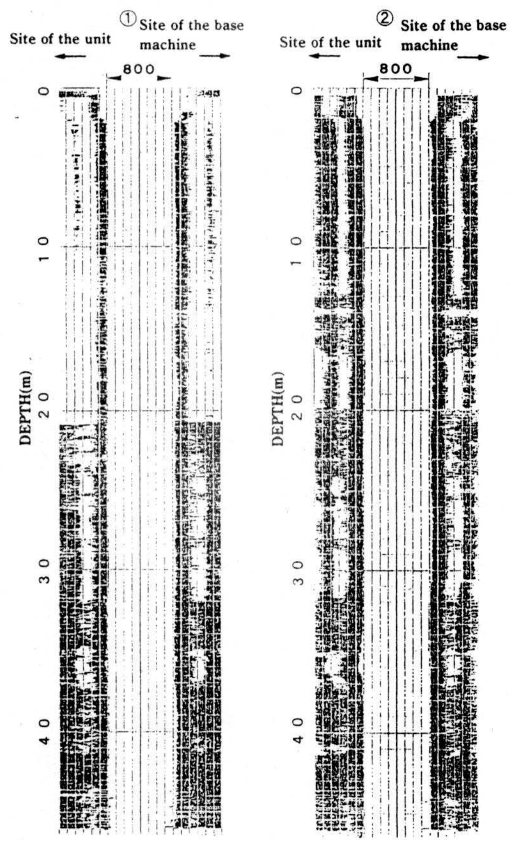



**Fig. 11 Result of ultrasonic trench sensor**

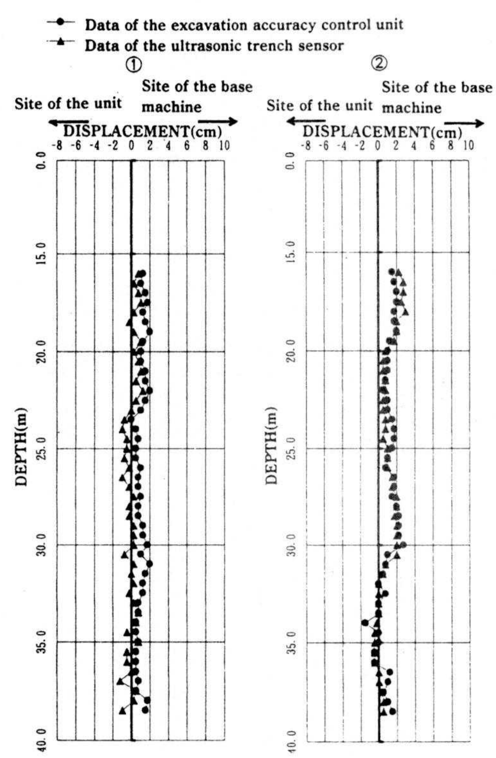



**Fig. 12 Comparison of values between the ultrasonic trench sensor and the excavation accuracy control unit**

## 6. CONCLUSION

The main results:

① The the primary excavation control unit is used for position control of primary excavation. The end of the cutter decides the position using the primary excavation guide, and the top of the cutter is controlled by boom movement. Thus it is highly effective for operation control.

② The excavation accuracy control unit has a mechanism which automatically follows cutter movement. Static ability test results showed reproduction regarding the initial value of the laser sensor and clinometer in response to the device to be excellent.

③ The operation control unit manages all data on excavation accuracy, and enables easy control of the adjustable guides by observing the display. During the field test, the unit clearly showed that information processing was superior, and that the data displaced was stable. Thus, the unit greatly enhanced operation.

④ The excavation accuracy control system functioned most effectively during the field test. Furthermore, the excavation accuracy control unit, the key to the system, allows for precise automatic follow. Checking the results of the ultrasonic trench sensor showed that the device was remarkable detection accuracy.

Since horizontal multi−axial rotating cutters were introduced to Japan, diaphragm wall depth has increased rapidly. This makes it essential to improve excavation accuracy and construction efficiency by supplementing standard equipment with a superior excavation accuracy control system. In this sense, it is most timely that we successfully developed our excavation accuracy control unit, one revolutionary in concept. This device enables keeping its detection wires vertical at all times. The unit is singular in concept, and demonstration proved its performance to be excellent.

In the future, the system should work with equal efficiency regardless of the type of ground excavated or the nature of the project in controlling cutters to a high degree of accuracy.