Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

Study of a New 3-D Measuring Method for Diaphragm Walls

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1. Introduction

Measurement of the shape of an excavated wall, which is one of the control items in diaphragm wall construction, is an absolute necessity during and after excavation in order to detect local surface collapse of the wall and areas of dissipation, and to control the final form.

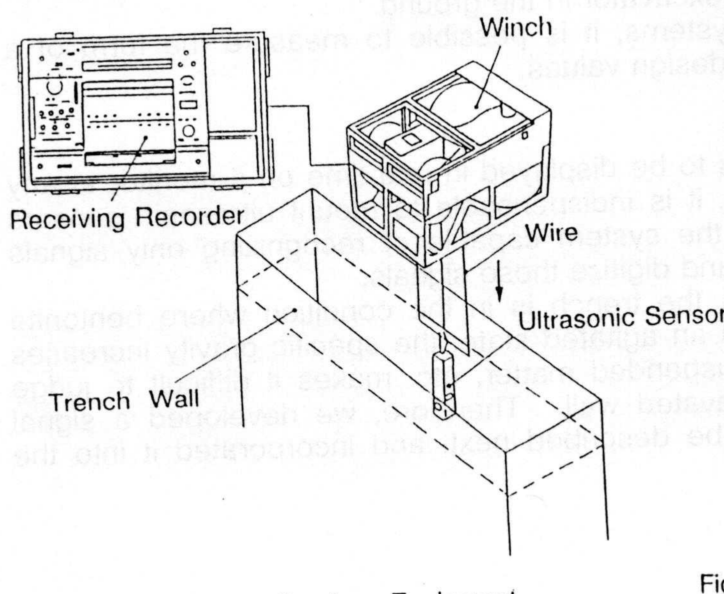


Fig. 1 Previous Equipment

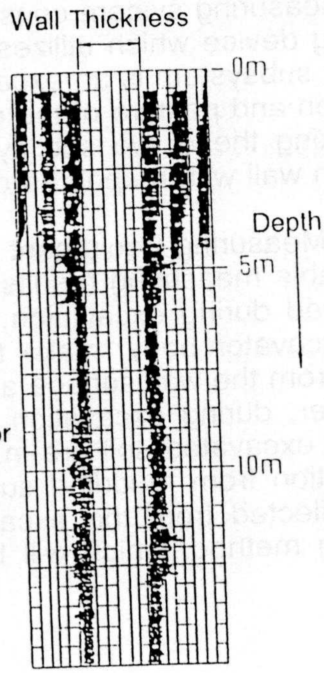


Fig. 2 Previous Output Diagram

As shown in Fig. 1, with previous equipment, a winch was set up on the trench wall and the distance to the wall was measured while lowering an ultrasonic sensor on a wire. The results obtained by this method, output on recording paper, are shown in Fig. 2. The following problems develop when excavation control using this equipment is attempted.

- ○ Since measurements can not be taken during excavation and the excavator must be pulled out of the excavation every 20~30 meters, it takes a lot of time and manpower to take measurements. It is also necessary to rely on the intuition and experience of the excavator operator for control during excavation.
- ○ A single measurement is capable of providing a measurement of the cross section of only the place where the sensor is lowered into the trench. In order to get a grasp of the wall as a surface, it is necessary to take multiple measurements. Records are also made by the distance signals from the ultrasonic sensor being output in analog form on recording paper. In order to determine distance, it must be read by people from the recording paper.
- ○ Ultrasonic signals tend to be attenuated considerably depending on the proportions of sand and clay in the excavated soil and reflected noise from suspended matter results in a poor S/N ratio and makes it difficult to distinguish wall signals.

In this report, we describe the measuring system which we developed for the purposes of eliminating these problems as well as saving energy in excavations and improving the system's reliability. We will also report on an on-site application example.

2. Outline of Measuring System

The measuring system consists of two subsystems. One subsystem is a 3-D measuring device which utilizes ultrasonics to measure the distance to the wall. The other subsystem is an excavator position measuring device which measures the position and posture of the excavator in the ground.

By linking these two sub systems, it is possible to measure the form of a diaphragm wall with respect to design values.

2-1 3-D Measuring Equipment

To enable measuring results to be displayed in real time on a monitor at any time desired during excavation, it is indispensable to mount ultrasonic sensors on the excavator body, make the system capable of recognizing only signals reflected from the wall surface and digitize those signals.

However, during excavation, the trench is in the condition where bentonite slurry and excavated soil are in an agitated state, the specific gravity increases and reflection from muddied suspended matter, etc. makes it difficult to judge signals reflected from the excavated wall. Therefore, we developed a signal processing method, which will be described next, and incorporated it into the system.

(1) Equipment Configuration

Fig. 3 shows the overall configuration of the measuring equipment. The 3-D measuring equipment consists of ultrasonic sensors mounted on the excavator body, a correction sensor (for measuring the velocity of ultrasonic wave propagation), a multiplexer (an ultrasonic wave sensor channel switching device), a relay for transmitting data, a transmitter and receiver on the ground for receiving and sending ultrasonic signals and a signal processing board. (These are in [ ] in the drawing.)

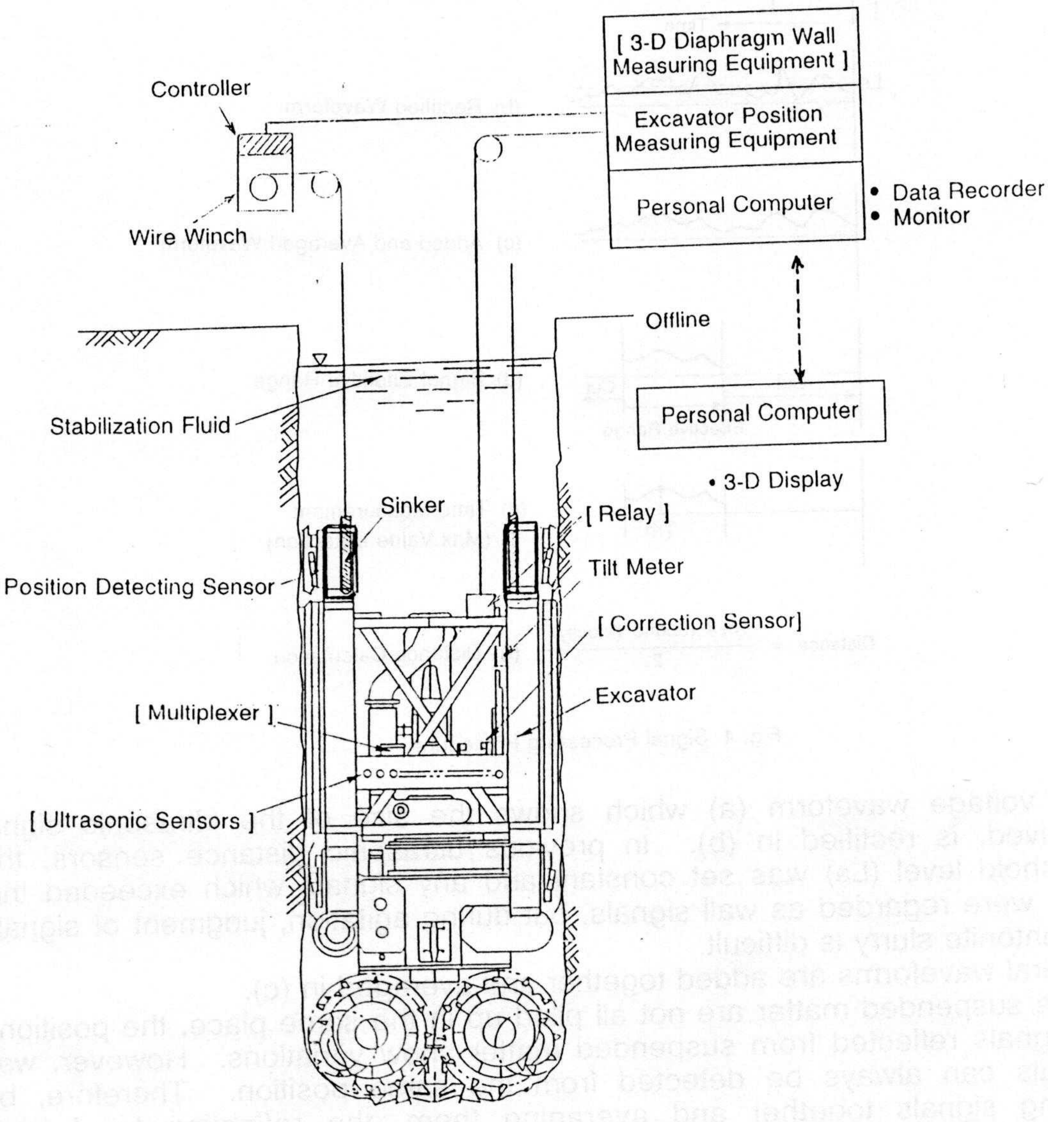


Fig. 3 Configuration of Measuring Equipment

(2) Signal Processing Procedure

For measurements, the multiple ultrasonic sensors mounted on the excavator are switched sequentially by a multiplexer, with each sensor measuring the distance from the sensor to the wall.

Fig. 4 shows the procedure for receiving and processing ultrasonic signals for each ultrasonic sensor in the form of a formula.

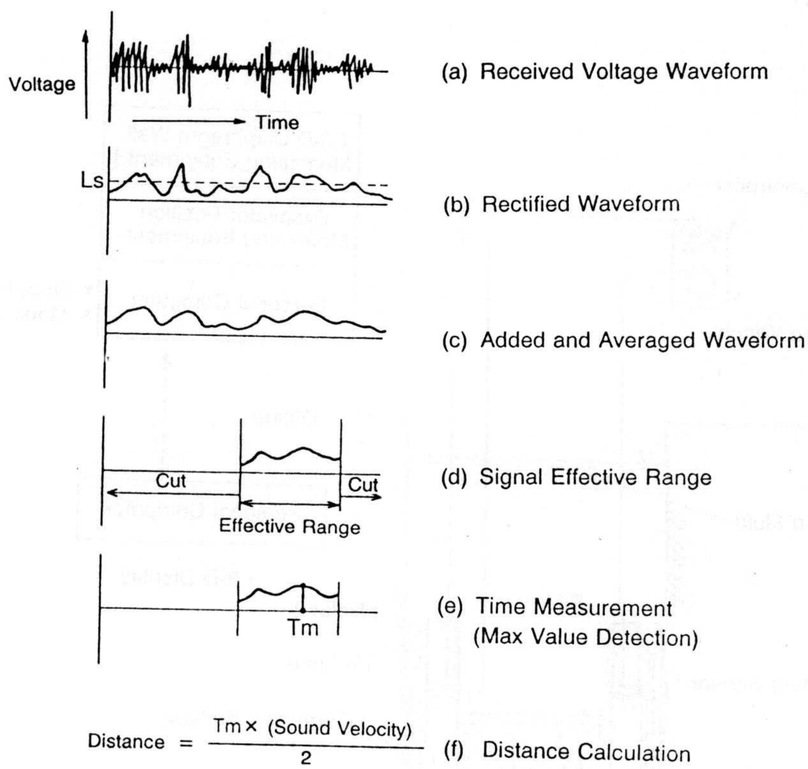


Fig. 4 Signal Processing Procedure

① The voltage waveform (a) which shows the size of the ultrasonic signal received, is rectified in (b). In previous ultrasonic distance sensors, the threshold level (Ls) was set constant and any signals which exceeded this level were regarded as wall signals, but during agitation, judgment of signals in bentonite slurry is difficult.

② Several waveforms are added together and averaged in (c).
Since suspended matter are not all piled up in the same place, the positions of signals reflected from suspended matter show variations. However, wall signals can always be detected from the same position. Therefore, by adding signals together and averaging them, the reflection level from suspended matter, etc. can be made relatively low.

③ The effective range of the reception signal is set according to the mounting locations of ultrasonic sensors on the excavator. (d)

④ Search is made for the maximum amplitude value of the waveform in the effective range (e) and the time Tm of that waveform is detected.
⑤ Using the ultrasonic wave propagation velocity v in slurry determined by the correction sensor and the value Tm, the distance to the wall is calculated.

Through this processing procedure, it becomes easy to judge between signals reflected from the wall and noise signals. That is, even if the level of the signals reflected by the wall is faint, if it is even a little higher than the noise level, then judgment between the wall signals and noise is possible. Digitizing of this processing system has been made possible by making it into a modular board which is mounted in an expansion unit of a personal computer.

2-2 Excavator Position Measuring Equipment

The 3-D wall measuring equipment measures the relative distance from the ultrasonic sensors mounted on the excavator to the wall. Therefore, in order to determine the form of the excavation with respect to the design excavation position for the diaphragm wall (plane and vertical), it is necessary to measure the position of the sensors, that is, the position of the excavator. Next, the equipment developed to solve this problem is described.

(1) Equipment Configuration

The excavator position measuring equipment consists of two sinker position detecting sensors mounted on the excavator body, two tilt meters, two sinkers suspended from ground level, two winch controllers, a data input/output device and display software. (Fig. 3)

(2) Measuring Procedure

Measurement is made by suspending a sinker, which acts as a reference, inside a position detecting sensor tube attached to the top of the excavator body on both sides and determining the relative position using contactless eddy current type distance sensors.

Next, the measuring sequence is described.

① The sinker is suspended in the sensor tube and acts as the reference point. (Fig 6) Up and down control of the sinker is accomplished by eddy current sensors (Z1, Z2). These utilize loop coils on the top and bottom of the sensor tube which sense the vertical position and feed it back to the servomotor driven winch at ground level. Thus this system is constantly following the movement of the excavator, working to keep the sinker in the measuring tube.
② The horizontal position of the excavator is calculated by measuring the position relative to the sinker (reference point) by means of eddy current sensors (X1, X2, Y1, Y2) located on the right and left sides at the front and rear of the measuring tube. (Fig. 5) In this way, the excavator's position with respect to the design value can be calculated.

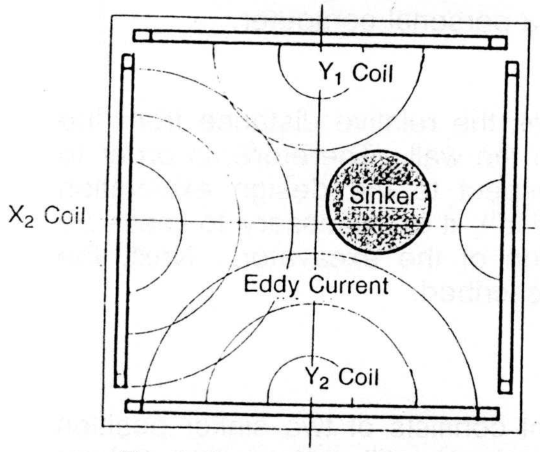


Fig. 5 Sensor Tube Plane View

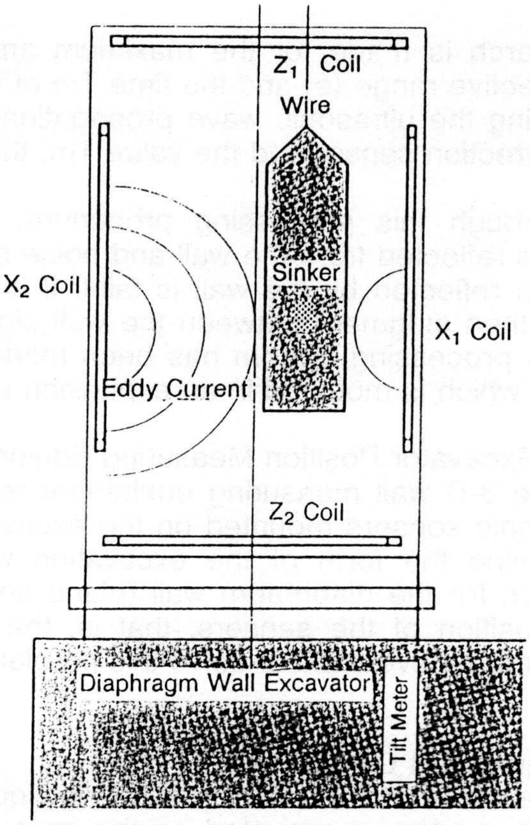
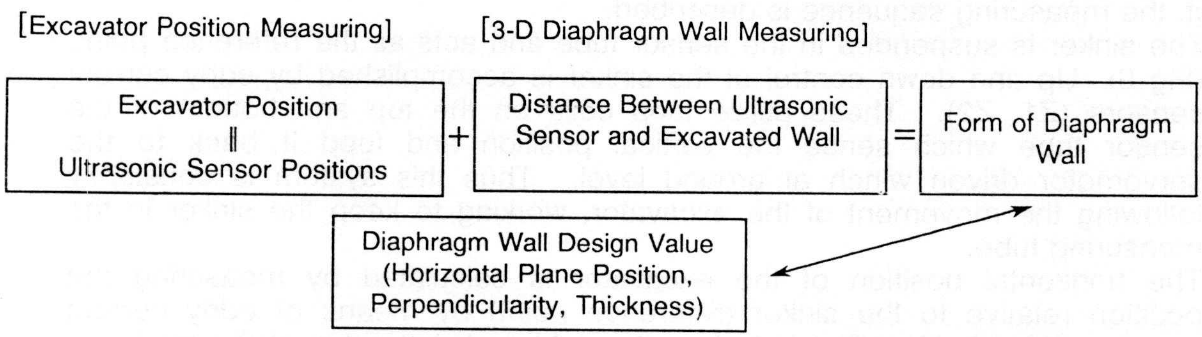


Fig. 6 Sensor Tube Sectional Drawing

2-3 Overall System

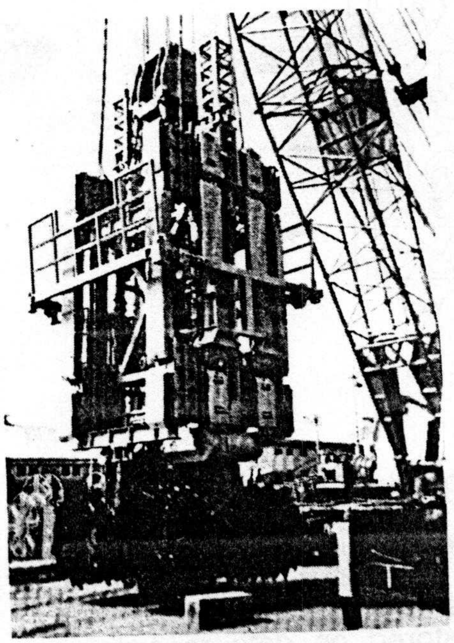
By combining 3-D diaphragm wall measuring equipment with excavator position measuring equipment, it is possible to control the form of the diaphragm wall according to the design value.
System specifications are shown in Table 1.



Overall System

Equipment	3-D Diaphragm Wall Measuring	Excavator Position Measuring
Measuring Precision	2cm	2cm
Measuring Range	200 cm (wall ~ sensor)	± 10cm
Possible Measuring Depth	150m	
Wall Thickness	70 cm or greater	
Display Software	Vertical Section, Horizontal Section, Contour Drawings, Bird's-eye Views	
Number of Channels	Max 20	2

Table 1 System Specifications



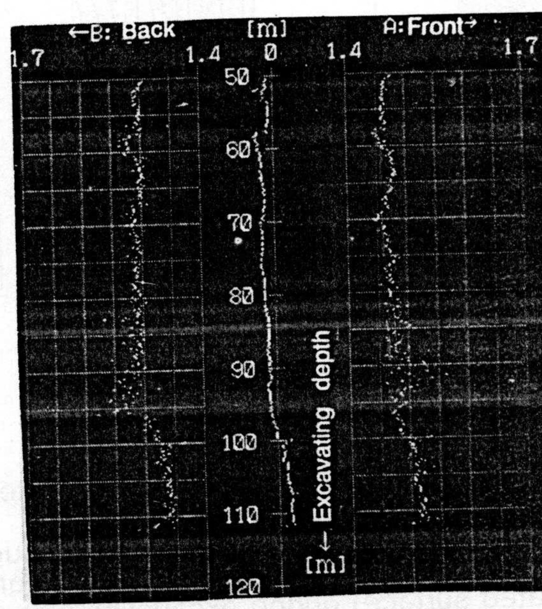


Photo 1 Excavator (Electro mill) Photo 2 Monitor Screen During Excavation

3. Application Example

We undertook studies of site requirements, the number of ultrasonic sensors needed, various display methods and other points and set out to build the optimum system.

This is an example of an application to an actual construction site.

The excavator where the system was installed was an Electro mill excavator (EM-320) and the application was made on a diaphragm wall construction located very deep underground with a design wall thickness of 2800 mm and an excavation depth of 120 m. The system is capable of monitoring the horizontal cross section or vertical cross section and the excavator position from the operation room, and selection can be made according to the needs of the operator. Photo 1 shows the excavator in which the system is installed and Photo 2 shows the monitor screen (displaying the vertical cross section and excavator position) during excavation. The excavation wall thickness and perpendicularity can be determined with good precision. Measuring data can be output offline to diagrams like those shown in Figure 7.

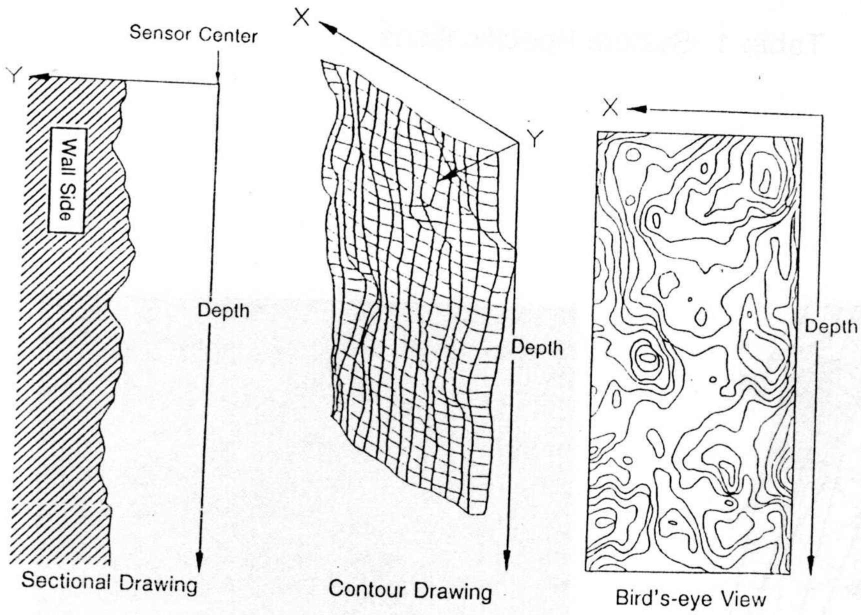


Fig. 7 Drawings

4. Conclusion

From the results of application of the system developed on this occasion, the following points were confirmed.

- The work of detecting work control values for determining the form of a diaphragm wall (indentations, protrusions and perpendicularity of the excavated surface) during excavation was made vastly more efficient.
- Since the measuring data can be digitized and stored on data recording media, sectional drawings, contour drawings, bird's-eye views and other diagrams can be output freely. The volume of earth excavated and other data can now be analyzed.
- Since the system's components were selected for their general purpose applicability, it is possible to build a system that is efficient for the needs of just about any construction job.

This system thus has made it possible to take the measurements needed in work control more efficiently and to automate this task. Thus, we think that the first stage in automating diaphragm wall construction has been completed. In the future, we are planning to study a system for feeding these measuring data back into the excavation operation.