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TRUST Method – Thin Slurry Walls

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ABSTRACT

TRUST is a construction method developed to build high-quality ultra-thin slurry walls mainly used to prevent ground water infiltration. TRUST 21 is a high-performance excavator which has been developed specifically for the TRUST method. The machine can install walls to a depth of 200 m with a thickness of 20 cm and is capable of operating in ground conditions ranging from alluvial soils to soft rocks. Position is controlled in real time with a laser position control system with a tolerance of 5 cm regardless of depth. Field experiments were carried out with favorable results.

INTRODUCTION

Slurry walls, which are designed to cut off or control ground water, have become an essential technique in the construction of underground structures. Recently, attention has been drawn to new applications of slurry walls, such as underground dams to develop underground water resources, and walls to prevent soil liquefaction, and to prevent pollution of ground water. In most of these slurry wall applications, steel sheet-piles, soil cement walls, or diaphragm walls are used. However, these options have their restrictions. For instance, when used as impervious walling, steel sheet-piles and soil cement walls are limited to a maximum excavation depth of about 20 m and 50 m, respectively. It is also difficult to obtain uniform quality along the length of the wall. At deeper locations, the jointing of elements is also often subject to deteriorated accuracy. On the other hand, the use of a diaphragm wall for impervious walling is uneconomic if the only purpose is to cut off water.

Given these disadvantages of the existing techniques, there has been much demand for a new type of slurry wall that is thin, highly economic, very reliable, and applicable at greater depths. In an attempt to satisfy this demand, Taisei Corporation launched research and development program for a new slurry wall system in 1989, resulting in TRUST 21, an excavator for thin slurry walls. This machine is able to carry out excavations in a wide range of soil types, ranging from alluvial soils to soft rock. The TRUST Method, a new technique for constructing slurry walls using this excavator, was later put into experimental use, thus completing the establishment of thin slurry wall construction technology.

1. CONSTRUCTION SYSTEM

1.1. Outline

This is a new excavation method based on slurry similar to existing methods using a rotary excavator for diaphragm wall construction. When carrying out excavations using the new method, earth removed by the cutters is removed as slurry through suction pumps placed above ground or by the air-lift method. The soil and slurry are then separated from the excavated mixture. The reverse circulation system is employed. After excavation, a solidifying agent previously prepared at the site is fed into the excavation through a feed port on the excavator. The slurry is replaced with the solidifying mixture to ensure even solidification as the rotating cutters agitate the mixture to distribute it evenly. This procedure is outlined in Figure 1.1.

Step 1: Excavation
Excavation is carried out with slurry to stabilize the excavated hole. A highly accurate positioning system is used to control the position of the excavator.

Step 2: Slime cleanup
As the excavation reaches the predetermined depth, the excavator is used to clean up slime deposited on the bottom of the trench.

Step 3: Solidification
The solidifying agent is fed through the excavator. The excavator is pulled upwards as more solidifier is added.

Step 4: Preceding panel construction
Construction of the panel is complete when solidification to the fixed height has been achieved. Every other panel is constructed initially; these are known as the preceding panels.

Step 5: Succeeding panels
Succeeding panels are constructed by excavating the ground between the preceding panels. Excavating slightly into the preceding panels enhances the water tightness of the joints.

Step 6: Completion of slurry wall construction
This procedure is repeated as often as required to complete a high-quality slurry wall.

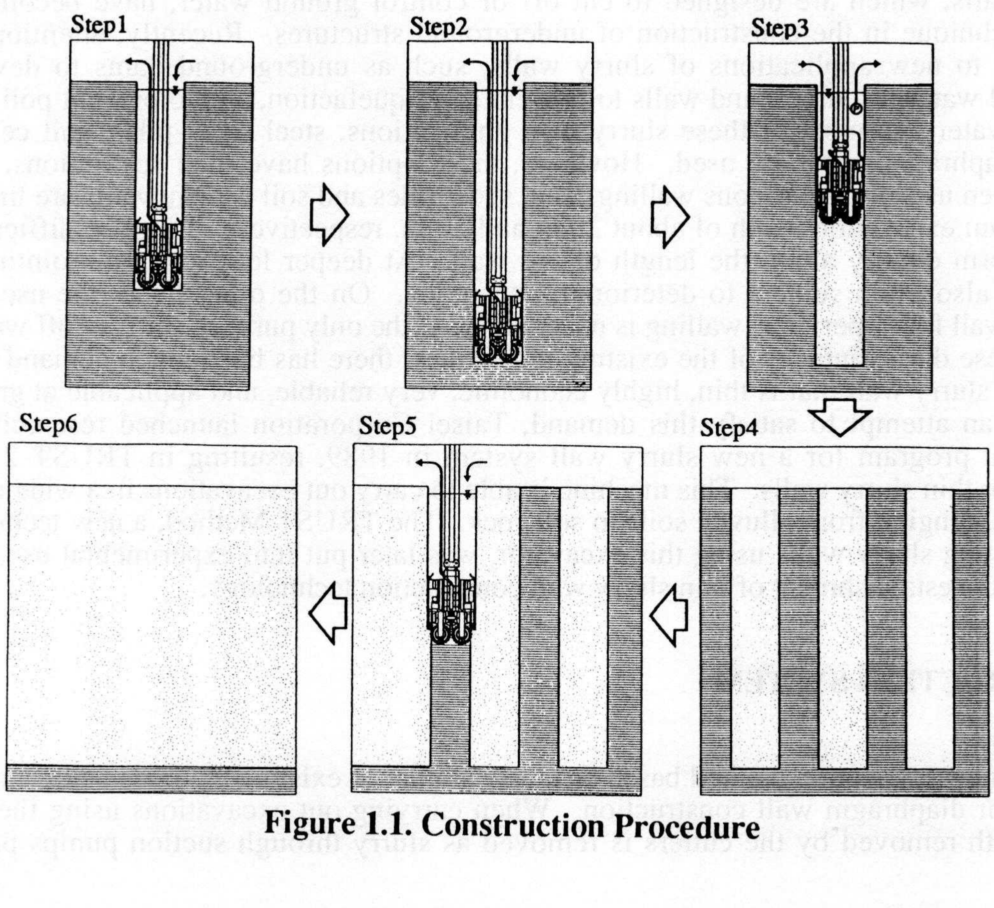

Figure 1.1. Construction Procedure

1.2. Excavator (TRUST-21)

Various investigations had to be carried out in the process of developing an excavator capable of building slurry walls as thin as 200 mm at great depth. In the end, a disk cutter with both side cutters and off-set bits was selected. A submersible pump was included in the first designs for the excavator, but several problems were posed by this idea; these included the need for a large pump housing, the consequent loss of ability to build thin walls, lack of sufficient frame strength, and extra weight.

In the present optimal design, the excavator is lifted down on a wire rope from the base machine on the surface. A submersible motor built into the excavator is powered via a conducting cable wound out from a reel. This motor turns the excavator's cutters through a mechanical power transmission. Using data on the absolute position and deviation of the excavator supplied by the precision positioning system, the excavator is able to control its position by operating the adjustable guides. The structure of the TRUST-21 excavator is illustrated in Fig. 1.2.

(1) Dimensions and weight of TRUST-21

The new TRUST-21 excavator is 3,980 mm wide and 7,318 mm high. It weighs 24 tf (21 tf in water), and is able to build slurry walls with a thickness of 200 mm at its narrowest point (600 mm at its thickest point). The size of the excavator is maximized within the frame strength. A 80 tf base machine is required at the surface to lift the excavator into place.

(2) Power

The excavator contains two 18.5 kW electric oil-sealed submersible motors, one on either side. These two motors can be operated independently, with speed controlled using an inverter control panel (22 kW x 2 units). Thus, during initial excavations or when working in soil with a gravel content that returns impact or vibration to the excavator, the motor can be slowed down and set at an optimum speed depending on ground conditions. A friction clutch mechanism is also fitted, to prevent gear damage during extremely high loading of the side cutters and off-set bits.

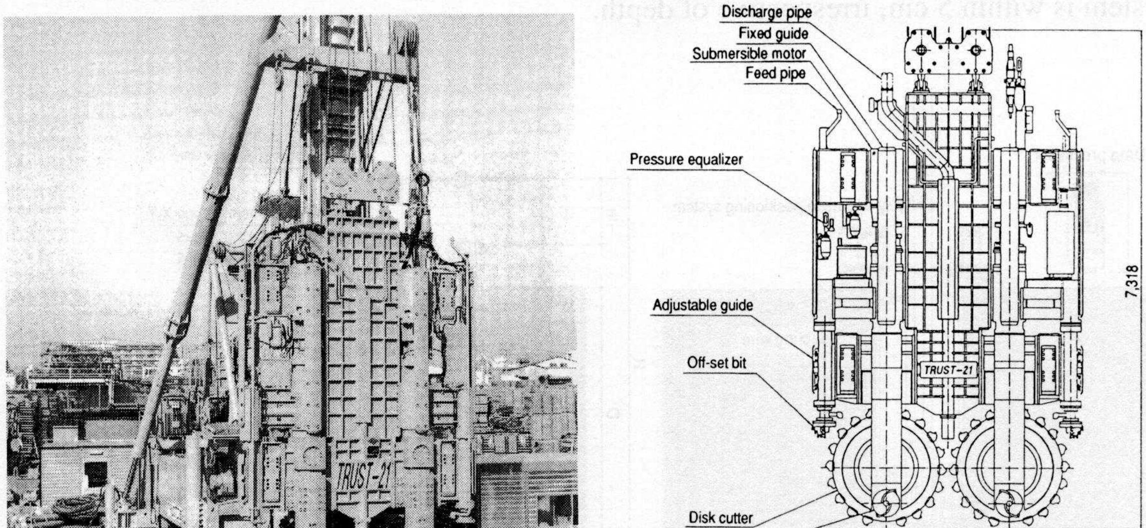

Figure 1.2. Photo and Structure of TRUST-21 Excavator

(3) Cutters

The cutters consist of two disk cutters for excavation of the major portion of the wall to a thickness of 20 cm, four side cutters which dig the space below the submersible motors' gearboxes, and two sets of off-set bits for excavating the overlaps between panels. These cutters can be used to excavate a wide range of ground types, from alluvial soils to soft rocks (qu=500 kgf/cm^2).

(4) Adjustable guides

There are adjustable guides at four locations on both the front and rear ends (eight positions in total) and at one position on either side of the excavator (two positions in total). These guides are electromagnetically operated hydraulic cylinders with a stroke of 50 mm. They can be used to control the excavator's position.

(5) Other features

The excavator is also fitted with a highly sensitive oil-filled pressure balancing system. This helps to balance the inner pressure against the water head, ensuring reliability of the seal. The motor casing is surrounded with a jacket for the circulation of cooling water, ensuring that the motor will not overheat under the loading imposed by mechanical agitation of the solidifying agent.

1.3. Accuracy management

Accurate construction of very thin slurry walls at great depths has been achieved by incorporating a highly accurate positioning system. The performance of this system has already been proven in its application to large-scale diaphragm wall construction for the Hakucho Bridge project and the Trans-Tokyo Bay Highway Project. As illustrated in Fig. 1.3, this precise positioning system is able to detect absolute position, twisting, and inclination of the excavator on a real-time basis. Wires are connected to the excavator for the purpose of position detection. A laser displacement gauge in the system then measures, with a precision of microns, how much the detection wires move as the excavator makes progress. Based on the data obtained in this way, any twisting or inclination of the excavator can be corrected by operation of the adjustable guides. The positional accuracy resulting from use of this system is within 5 cm, irrespective of depth.

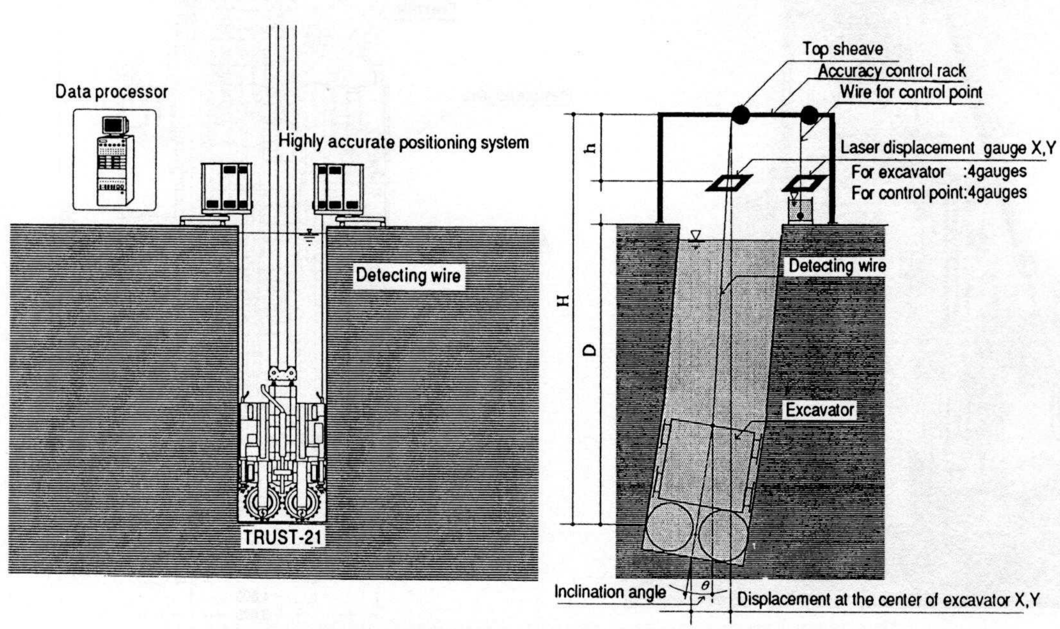

Figure 1.3. Highly Accurate Positioning System

1.4. Slurry

Two types of slurry are generally used in the excavations: bentonite slurry and polymeric slurry. The best slurry for a particular situation is selected according to ground conditions and construction needs. The important factor in making the choice is to ensure that the slurry adopted is adequate to prevent cave-ins in the excavated trench and can be easily separated from the excavated material. Where succeeding panels are to overlap a portion of the preceding panels, it must also be remembered that the slurry will deteriorate as calcium eludes from within the solidifying agent. The proportions of slurry constituents used during the demonstration experiments are tabulated in Table 1.1 for reference.

Table 1.1
Slurry Constituents

Water	Bentonite	CMC	Dispersing agent
1,000 kgf	60.0 kgf	0.5 kgf	1.0 kgf

1.5. Solidification

Bentonite slurry was used during our experiments. The slurry which is used during excavation is separated from the excavated material and mixed with a cement solidifying agent in a batcher plant. The excavator is lowered to the bottom of the excavation. The solidifying agent previously mixed at the surface is then fed through the feed ports on each side of the excavator into the excavation shaft, thereby replacing the slurry. As soon as the excavator is submerged in solidifying agent, it is hoisted up as far as necessary according to the volume of agent added. As the excavator is hoisted up, the cutters are rotated to agitate the agent, preventing localized hardening and ensuring even solidification. The proportioning of solidifying agent varies depending on the target strength and the permeability coefficient. Table 1.2 shows the proportions of solidifying agent used in the demonstration experiments.

Table 1.2
Proportions of Solidifying Agent

Bentonite slurry	Cement solidifying agent
1,000 liters	250 kgf

2. DEMONSTRATION EXPERIMENT

2.1. Purpose

The purposes of this experiment were to establish a technology for use of the TRUST method and to confirm the water cut-off performance of finished walls. The experimental construction is in the form of a square consisting of four elements, as shown in plan view in Fig. 2.1. The ground conditions at the experimental site are shown in the form of a stratigraphic section in Fig. 2.2. The ground comprises layers of loam, clay, fine, medium-fine, and coarse sand, and gravel. This can be considered the most suitable ground for testing the performance of this method. Excavations were made to a depth of 28 m below the surface to check the permeability of the finished wall. The impermeable barrier was to extend to a depth of around 25 m, below which lies a clay layer. A further 3 m was thus dug into the clay layer, for a total excavation depth of 28 m. In the case of one panel only, the ground was excavated down to 100 m to check the ability of the excavator.

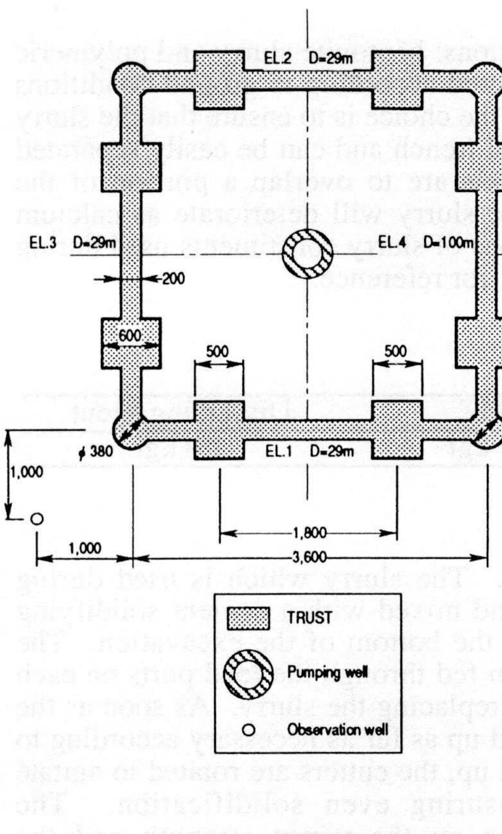

Figure 2.1. Panel Arrangement

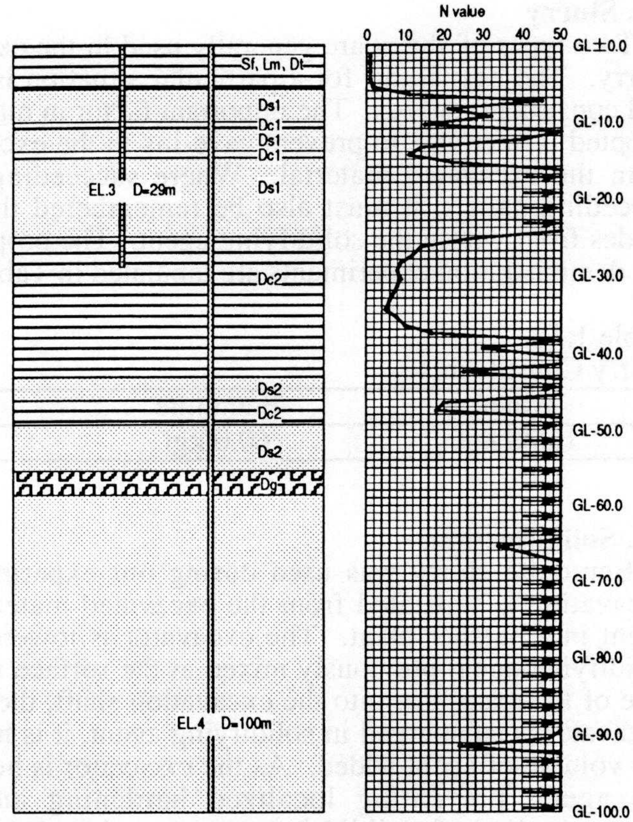

Figure 2.2. Stratigraphic Section of the Test Ground

2.2. Experiment Results

(1) Excavation efficiency

A regression analysis of N-values against excavation rate for each type of soil revealed that excavation velocity may be classified by the N-value of the soil. This is shown in Table 3.1.

Table 3.1
Excavation Rate by Soil Type (Average for All Panels)

Soil type		Actual excavation rate (m/Hr)	Remarks
0<N<50	Sandy	3.5-5.0	
	Clay	4.0-5.0	
50≤N	Sandy	2.5-3.5	
	Clay	3.0-4.0	
Gravel		4.0-5.0	(Maximum gravel size: 50 mm)

The real excavation rate is defined as the gross excavation rate plus the time taken to connect the slurry discharge pipe, correct the excavation, and circulate slurry in the excavation.

The data obtained here are not based on a range of application examples, so the resulting excavation rate may not fully reflect the performance of this method. However, this data will be a contribution to future analysis with more data.

(2) Excavation accuracy

In this experiment, we were able to control the excavator to within the target of 5 cm using the highly accurate positioning system. The results of slurry trench measurements made with an ultrasonic instrument after reaching the target depth (for the 100 m-deep panel) are shown in Fig. 3.1. These results indicate that the displacement error at the center of the excavator in EL. 4 was within 40 mm at a depth of 100 m. Thus the overall accuracy is better than 1/2,500. In Fig. 3.2, the ultrasonic data and the excavation records from the positioning system are compared. The center displacement as measured by both methods, ignoring collapsed sections of the trench wall, indicates a maximum discrepancy of about 1 cm, and the correlation is very good. Our conclusion, therefore, is that excavation using this precise positioning system ensures an accuracy of better than 50 mm regardless of the depth.

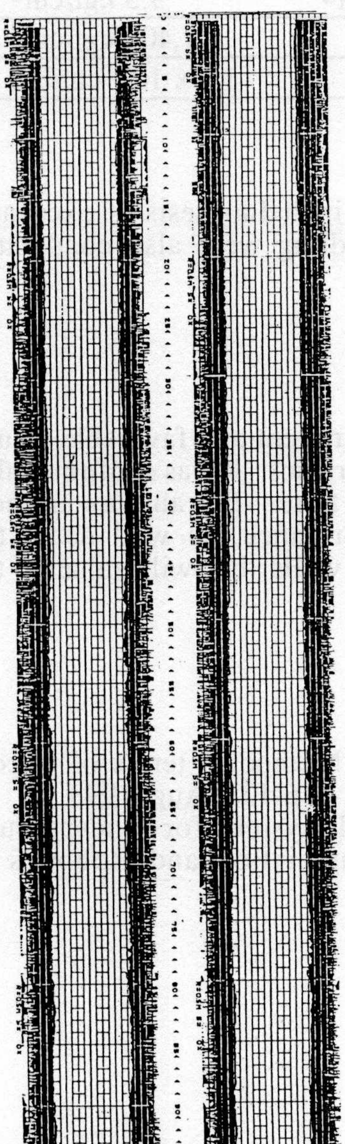

Figure 3.1. Ultrasonic Trench Wall Measurement Results

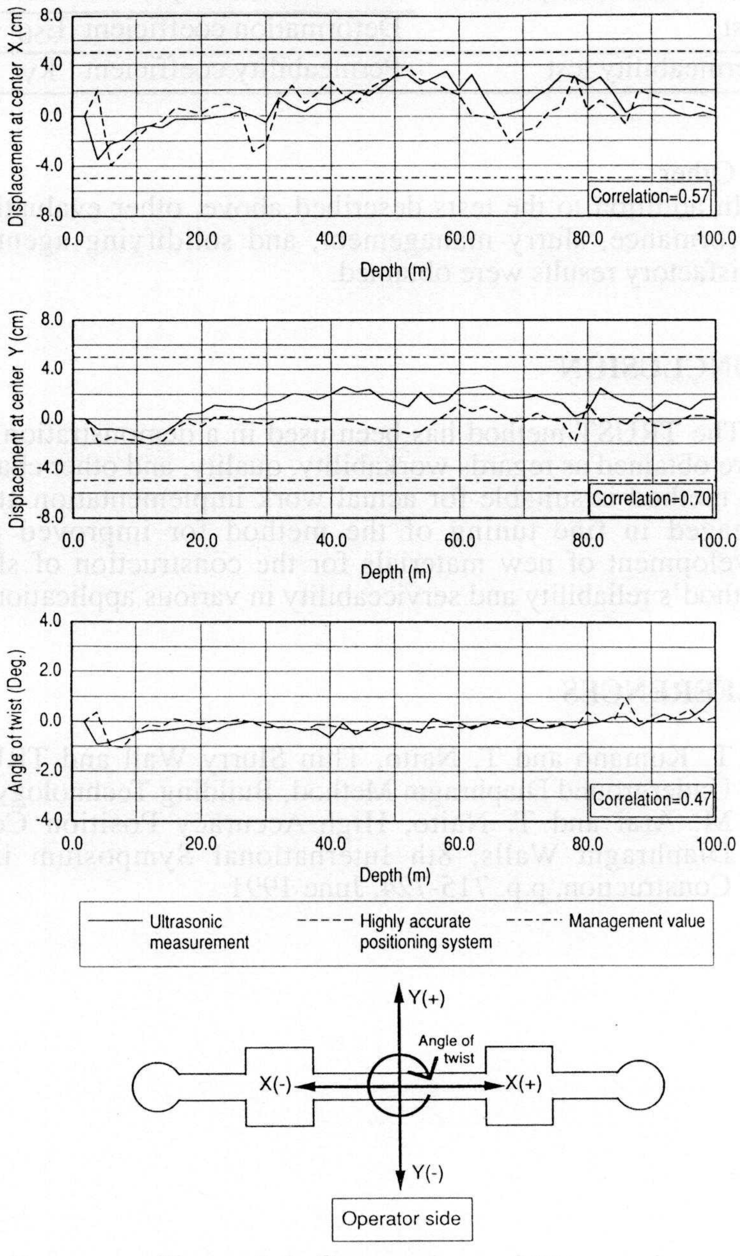

Figure 3.2. Comparison of Ultrasonic Measurements and Positioning System Records

(3) Quality evaluation

The main focus of the quality evaluation of the TRUST method was its cut-off performance, and this was the main purpose of the experiment. The water level within the TRUST walls was lowered to observe its recovery rate at the site to obtain a permeability coefficient. A core sample from the wall was also subjected to an unconfined compression test and a permeability test. The results of these tests are given in Table 2.1.

Table 2.1
Results of Quality Tests

Test	Physical value	Value
Water pumping test	Permeability coefficient k_H	1.3 x 10^{-6} cm/sec
Unconfined compression test	Unconfined compression strength qu	9.3 kgf/cm^2
	Deformation coefficient E_{50}	1,400 kgf/cm^2
Permeability test	Permeability coefficient k_V	1.6 x 10^{-6} cm/sec

(4) Other

In addition to the tests described above, other evaluations, including tests of excavator performance, slurry management, and solidifying agent handling were also conducted. Satisfactory results were obtained.

CONCLUSION

The TRUST method has been used in a demonstration experiment and favorable results were obtained as regards workability, quality, and other characteristics. It was confirmed that the method is suitable for actual work implementation at any time. The authors are now engaged in fine tuning of the method for improved performance, as well as in the development of new materials for the construction of slurry walls that will enhance the method's reliability and serviceability in various applications.

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