Development of the Automatic System for Pneumatic Caisson

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ABSTRACT

The pneumatic caisson method is applicable in any type of ground and permits the ground being excavated to be observed directly, hence it provides a reliable foundation. However, since the working chamber is put under high pressure, high temperature, and high humidity, this method requires robust, experienced workers.

On the other hand, the aging of skilled workers and the shortage of younger workers have become a social problem in these years. This is especially serious in foundation work using the pneumatic caisson method which involves hard work under high pressure.

In view of the above situation, the Ministry of Construction conducted a joint research with several private companies on technology for automatically removing excavated materials in the pneumatic caisson method as part of its comprehensive technical development project and has come up with a new pneumatic caisson method.

1. INTRODUCTION

In the pneumatic caisson method, as the caisson is sunk deep in the ground, the workers in the working chamber are exposed to the danger of the "bends" (a disease caused by high pressures). Besides, the safe continuous working hours decrease and the work efficiency declines.

In order to improve the working environment and make the method applicable to foundation work deeper in the ground by eliminating manual labor in the working chamber, it was necessary to develop suitable technology.

Though technology for automating the removal of excavated materials from the working chamber has been developed, there was need to improve its workability and efficiency.

Under those conditions, the Ministry of Construction carried out a joint research with several private companies on technology for automatically removing excavated materials in the pneumatic caisson method as part of its comprehensive technical development project "Development of New Technology for Work Execution in the Construction Industry" (fiscal 1990 to 1995) and developed an automatic soil removal system which eliminates a series of operations in the working chamber, from excavating the ground at the bottom of the caisson to transporting the excavated materials to the ground surface.

2. OUTLINE OF THE NEW METHOD

The new pneumatic caisson method has been developed for an oval-shaped caisson having a cross-sectional area of 200 m^2 and an excavating depth of about 40 to 50 m. With the new method, it is possible to remove excavated material (natural ground) at a rate of about 10 m^3 per hour even at the deepest part.

In the new method, the equipment consists of an excavating system, soil transfer system, and ground conveyor system. They are remote-operated by wire or automatically controlled from a control room on the ground.

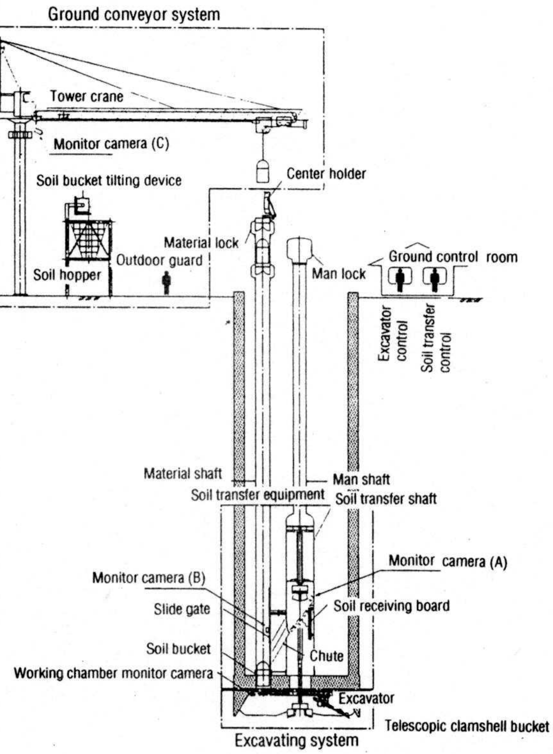

Fig. 1 Concept of new pneumatic caisson method

3. DETAILS OF THE EQUIPMENT

As mentioned above, the equipment consists of (1) excavating system, (2) soil transfer system, and (3) ground conveyor system. Each of the systems is described in detail below.

3.1 EXCAVATING SYSTEM

Recently, as more and more larger-scale caissons are used, the excavation work in the working chamber that was formerly dependent on manual labor is being mechanized.

The excavator employed in the new method is an overhead traveling type whose wheels are driven by a hydraulic motor to run on two rails installed to the ceiling of the working chamber. This excavator is remote-operated by wire from the ground control room. It is also capable of automatic operation. Details of the excavator used in the working chamber are shown in Fig. 2.

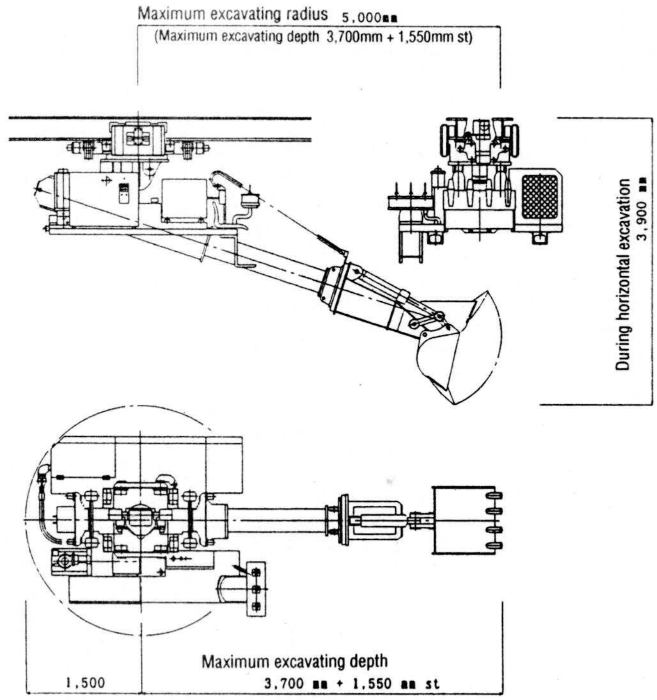

Fig. 2 Example of excavator in working chamber

3.2 SOIL TRANSFER SYSTEM

The soil transfer system installed in the working chamber automatically puts exavated materials in a soil bucket. It consists mainly of a telescopic clamshell bucket, soil receiving board, chute, and slide gate. Details of the soil transfer system are shown in Fig. 3.

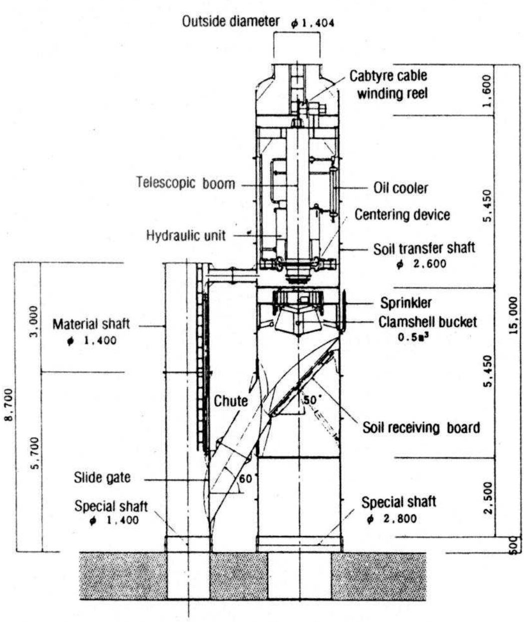

Fig. 3 Concept of soil transfer system

The telescopic clamshell bucket is a hydraulic clamshell bucket installed to the end of a telescopic rod. Since the bucket does not sway much while it is raised or lowered and a vertical reaction is applied to it during operation, it is capable of scooping excavated materials securely. The bucket capacity is 0.5 m^3 (Fig. 4).

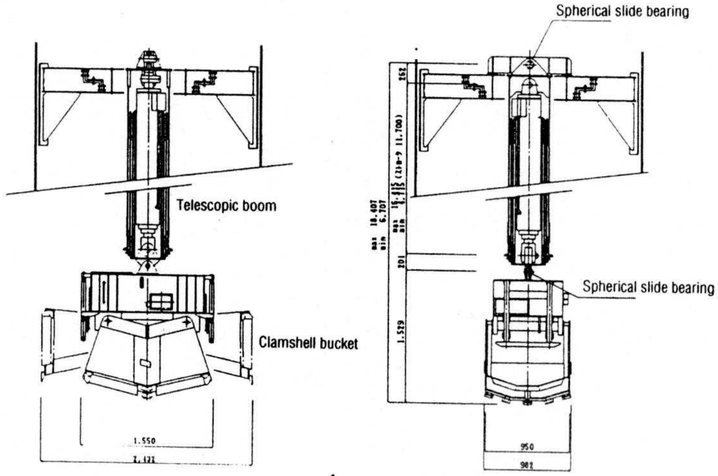

Fig. 4 Telescopic clamshell bucket

The soil receiving board is operated by a hydraulic jack. It is opened downward while the clamshell bucket is scooping excavated material. When the clamshell bucket discharges excavated material, the soil receiving board is closed upward by the hydraulic jack at the time when the clamshell bucket rises to its highest position. Thus, the soil receiving board receives the excavated material fallen from the clamshell bucket and leads it to the chute (Fig. 5).

The chute temporarily holds excavated material till it is put in the soil bucket. The amount of excavated material held by the chute is three clamshell bucketfuls, or 1.5 m^3. The slide gate opens upward to transfer excavated material which has been temporarily held in the shaft to the soil bucket when the excavated material held reaches a prescribed amount.

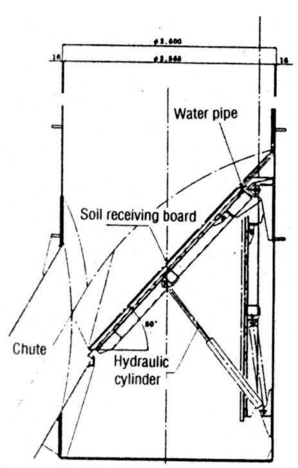

Fig. 5 Soil receiving board

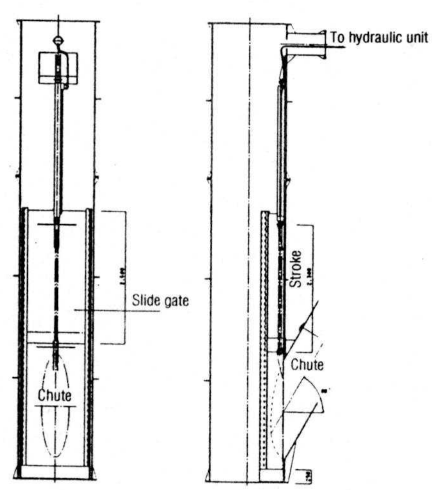

Fig. 6 Slide gate

3.3 GROUND CONVEYOR SYSTEM

The ground conveyor system for excavated materials consists mainly of a soil conveyor crane, soil hopper, soil bucket, and automatic soil bucket tilting device. As the soil conveyor crane, a crawler crane or a stationary tower crane, whichever is suitable for particular field conditions, etc., can be used.

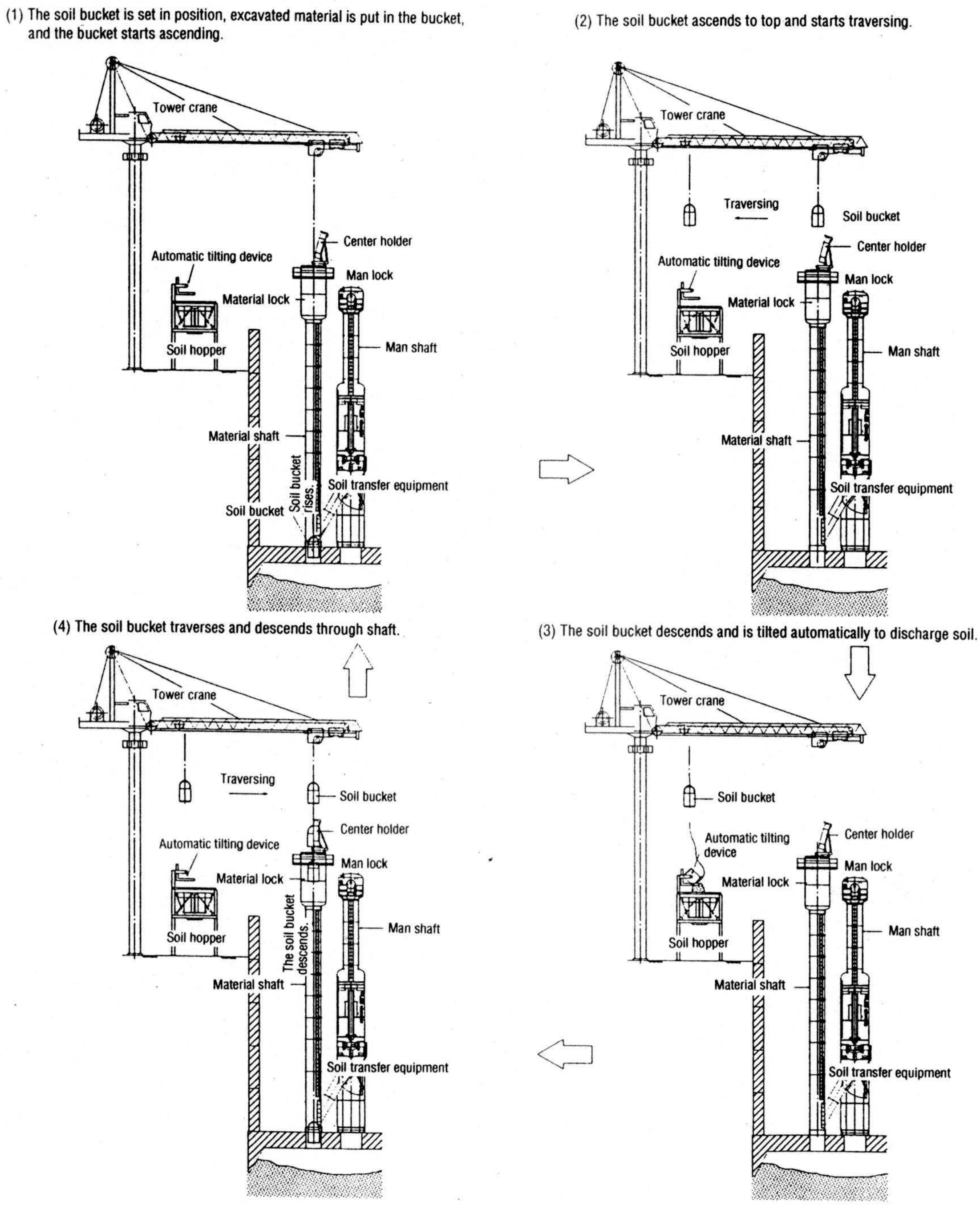

Fig. 7 Automatic discharge of excavated materials

The flow of automatic discharge of excavated material is shown in Fig. 7. All these operations are remote-controlled from the ground control room or controlled manually.

In the remote control mode, the individual devices (soil transfer equipment, crane, and material lock) are operated automatically by interaction between computers built in their control units and the host computer installed in the ground control room.

In addition, the ground control room has CRTs for display of position data and monitor TVs for operation check.

4. IMPLEMENTATION OF BASIC EXPERIMENTS

Basic experiments were carried out to check the performance of the individual systems, as well as the soil discharging performance of the soil transfer system, and to obtain data necessary for determining design details. They consisted of a preliminary experiment and a full-scale experiment. In the preliminary experiment, the performance of high-molecular resins which could be used to prevent clayey soil from sticking to the soil receiving board was examined using a simple indoor test apparatus.

In addition to three types of high-molecular resins, iron and stainless steel materials were tested. From the test results, it was found that even iron and stainless steel materials were as effective as high-molecular resins as long as the soil receiving board surface was kept smooth and wet.

In the full-scale experiment, the functions of the individual components of the soil transfer system were checked using actual-size equipment (Photo 1). The check items and results of the experiment are shown in Table 1.

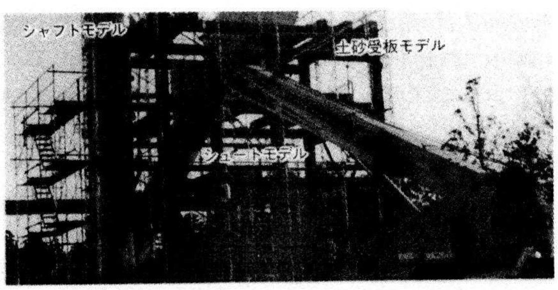

Photo 1 Apparatus for basic experiments (present experiment)

Table 1 Items and results of basic experiments

Device name	Experimental item	Experimental results
Soil receiving board	Optimum tilting angle	50°
Chute	Optimum tilting angle	60°
Slide gate	Durability	Need for structural reinforcement
Soil bucket	Condition of soil transfer to bucket	Good
Prevention of sticking of soil	Optimum preventive measure	Water sprinkling
Control sensor	Positioning accuracy	Selection of right sensors at right places

To determine the optimum installation angles of the soil receiving board and chute, the conditions of soil sliding over or sticking to them were examined by varying the height of fall of soil (Photo 2).

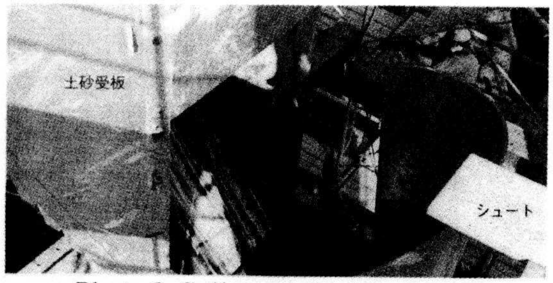

Photo 2 Soil receiving board and chute

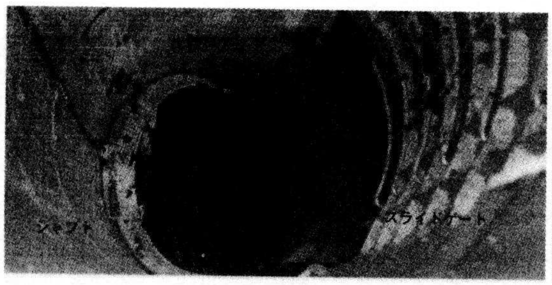
Photo 3 Slide gate

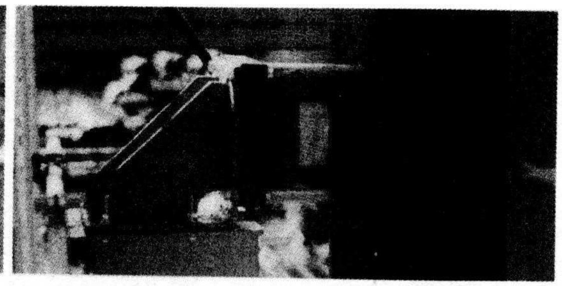
Photo 4 Soil bucket control sensor

With respect to the soil receiving board, the inclination was varied between 45 and 60 degrees. As far as the experimental results are concerned, the inclination did not make any marked difference. However, the optimum angle of installation was assumed to be 50 degrees based on the time required for soil to slide over the chute and the size of the actual equipment.

As for the chute, the inclination was varied between 50 and 70 degrees. According to the test results, the soil sliding speed was faster and the amount of soil sticking was smaller at 60 degrees than at 50 degrees. At an inclination of 70 degrees, the soil sliding speed over the chute was so fast and the sliding energy was so large that the soil was occasionally compacted to such a degree that the slide gate would not open. In view of the condition of soil held by the chute, as well as the time required for the soil to slide over the chute when the slide gate is opened and the size of the actual equipment, the optimum angle of installation of the chute was judged to be 60 degrees.

As to the slide gate, it was judged that the slide gate had no structural problem concerning the impact from the soil. However, since the tensile force of the hydraulic cylinder was considered insufficient, it was decided to increase the tensile force of the hydraulic cylinder for the actual equipment.

As measures to prevent excavated material from sticking to the soil receiving board and chute, the application of a high-molecular resin and the sprinkling with water were tested. The test results showed that the application of a high-molecular resin was really effective. However, high-molecular resins have the problem of being easily damaged by gravel contained in excavated material. By contrast, water sprinkling washed away the soil quickly and almost completely. Therefore, it was decided to employ water sprinkling in the actual equipment.

Based on the above results of the basic experiments, details of the system were discussed and a soil transfer system was designed. Then, an actual system was built and the operation of each of its components was tested in the factory (Photo 5). The test results proved that all the system components operated smoothly.

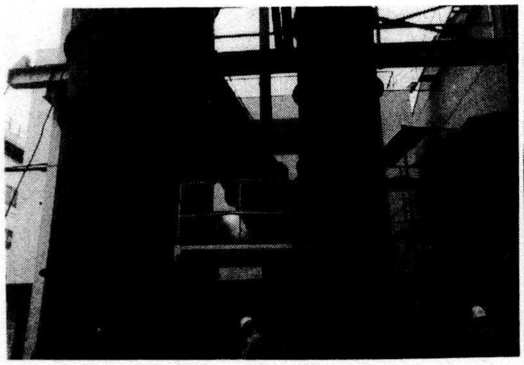

Photo 5 Scene of operational test in plant

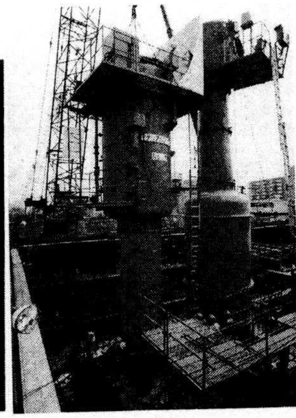

Photo 6 Scene of on-site assembly

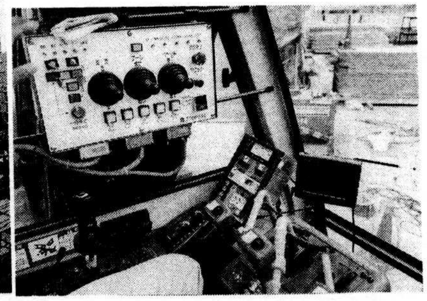

Photo 7 Automatic crawler crane

5. EXECUTION OF DEMONSTRATION WORK

In order to ascertain the workability of the new pneumatic caisson method, demonstration foundation work was executed in the field in fiscal 1995.

In the work, a pneumatic caisson was used for a bridge spanning a river. Used as a bridge pier foundation, it has a cross section 9.1 m by 20.1 m and a depth of 33.5 m.

The purpose of the demonstration work was to check the functions of the individual systems used in the new method and validate the whole system and work procedure.

The main points checked in the demonstration work are shown in Table 2.

Table 2 Items checked during demonstration work

	Item	Check points
General	Total system	Control programs
		Specifications of system components
	Work efficiency	Cycle times of individual parts
		Ease of operation and safety
	Impact on the environment	Noise and vibration
Soil transfer equipment	Soil receiving board	Optimum tilting angle
		Durability (wear resistance)
	Slide gate	Opening/closing performance (tensile force)
		Durabiliry
	Soil bucket	Adaptability to automatic operation
		Bucket shape
	Prevention of sticking of clayey soil	Optimum sprinkling rate
	Sensors	Operational accuracy
		Optimum installation positions
	Clamshell bucket	Natural ground excavating force
		Gripping force
		Cylinder wear resistance

An automated crawler crane was used to remove excavated materials in the demonstration work.

6. CONCLUSION

At present, manuals for work execution and estimation are being compiled for practical use of the new pneumatic caisson method. In the future, we intend to make an in-depth study of the system based on the results of execution of the demonstration work and complete practical manuals.