GROUND-LEVEL REMOTE CONTROL SYSTEM FOR PNEUMATIC CAISSON

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ABSTRACT

Pneumatic Caisson is characterized by its unique working condition that the working site is full of compressed air. Therefore, as the pressure goes up, working efficiency deteriorates because of being restrained by the environmental and safety factors of site conditions. Thus, as the excavation depth gets deeper, the working conditions get much severer. So, execution in the great depth has been said to be difficult or almost impossible.

Kajima Corporation and Shiraishi Corporation jointly developed "The Ground-Level Remote Control System for Pneumatic Caisson", which can control operation, excavation, sinking and settlement for all pneumatic caisson construction works from an operation room located at ground surface. With the implementation of this system, the necessity for workers to be subjected to a highly pressurized environment has been reduced greatly. Tokyo Electric Power Co., Inc. applied this system to site work and solved various problems particular to pneumatic caisson.

The features of the system are as follows:

1) Remote control of equipment in the pressurized chamber
2) Automatic operation of electric-powered hydraulic excavator
3) Observational monitoring and measuring system

This paper presents development process, system outline, developed techniques, and application at the site.

1. Introduction

As the Pneumatic Caisson is executed on condition that ground water is drained by using compressed air, air pressure in the working site gets higher in proportion to depth. When air pressure gets higher, not only the safety and environmental conditions deteriorate, but also work efficiency is restrained along with reduction of real operating time.

For example, when a man works in a pressurized chamber which pressure is $2kg/cm^2$, his maximum workable time is only 5 hours a day. Moreover, in the same way, maximum workable time is only 3 hours a day in the $3kg/cm^2$ pressurized chamber, and is only 2 hours a day in the $4kg/cm^2$ pressurized chamber. In addition, it is inevitable for him to be exposed to danger of suffering from decompression sickness or other caisson diseases.

But, Pneumatic Caisson Method has an advantageous position in foundation work by reason of its unique merits which other methods do not have. Recently, the utilization of underground space is attracting attention, and the construction of great depth and large-sized structure are in demand.

Consequently, "Remote Control System" was developed, and applied to site work of Tokyo Electric Power Co., Inc., which enabled the operation of all pneumatic caisson work from the control room on the ground. Thus its merits were put to practical use and the pneumatic caisson work was executed efficiently and safely regardless of construction depth.

2. System development

2-1. Development plan

The initial concept is as described below.

As shown in Fig. 1 and Fig. 2, the excavator, which is already developed and has a capacity of $0.15m^3$, is suspended from the parallel rails installed under the concrete slab, and can travel over freely. The automatic soil feeder, already developed too, can stock 1 m^3 of diggings on its belt conveyer, and loads it in the earth bucket.

But various problems were found, such as, when an operator tries to control the machines only by TV monitoring and without seeing directly, the TV monitoring method limits his information than what direct seeing method gives. Putting the problems concretely, they are described as follows:

1) Can an operator control excavator safely and freely ?
   An operator finds many dead angles, if he monitors only through the TV cameras. And the picture on TV screen does not have 3-dimensional effect. So it is difficult to control complicated operation.
   It is hard to comprehend relative position of caisson and excavator, and excavator's posture. So there is danger that the excavator may collide with other equipment or caisson.
2) Can an operator grasp the excavating progress in the pressurized chamber, especially that of cutting-edge part ?

Therefore, in order to solve aforementioned points at issue, three new techniques were developed, and the Remote-Control System was created by integrating them with techniques which have been already developed and are in practical use.

Three new techniques are as follows:

1) Full automatic operation system of excavator
2) Realtime monitoring system of excavator's movement
3) Measuring system of excavating progress

Needless to say, these three systems are operated, controlled and monitored from the control room on ground surface.

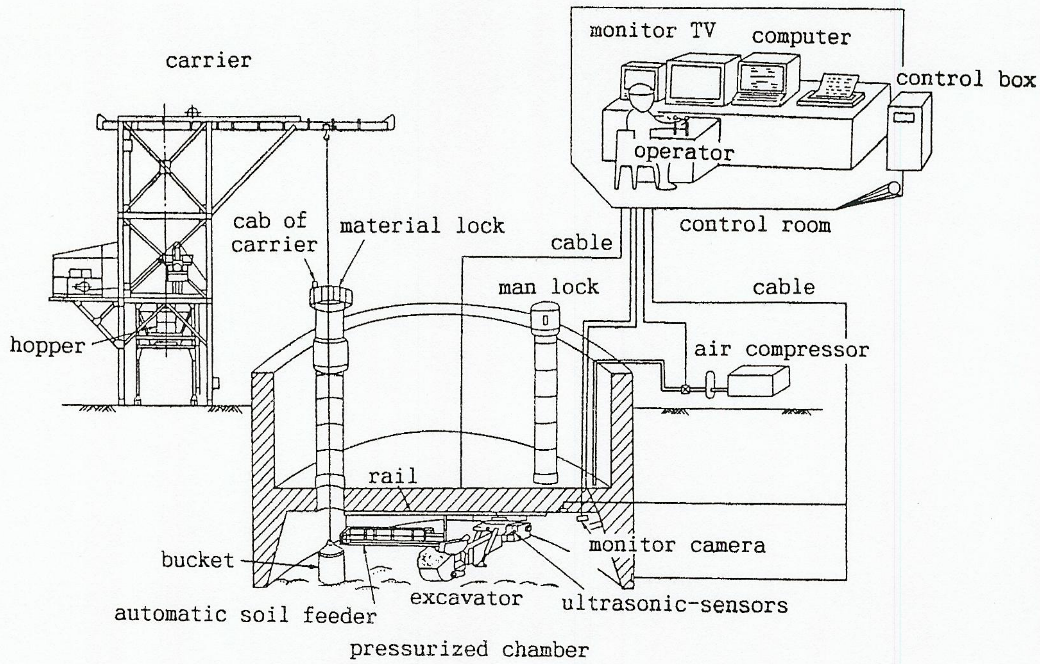

Fig. 1 Ground-level remote control system for pneumtic caisson

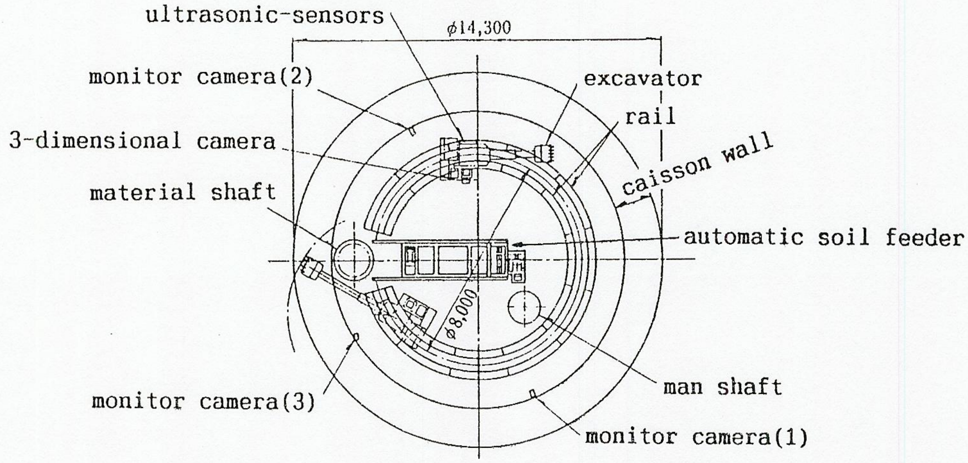

Fig. 2 Layout of equipment in the pressurized work chamber

2-2. Outline of newly developed techniques

1) Full automatic operation of electric-powered hydraulic excavator

There was no other means of excavating the ground but to operate the excavator by manual remote control using the TV monitor. But routine excavator operation involving simple and repetitive motions do not require any special judgement to be made by the oparator. So it can be changed into automatic operation system. The movement of loading excavated material into the automatic soil feeder requires no special judgement, and can easily be defined that the excavator moves from an unspecified point (excavating) to a fixed point (loading). Therefore, it was concluded that this movement of the excavator can be changed into automatic operation, which is greatly effective in this case.

A diagram of automatic operation is shown in Fig. 3.

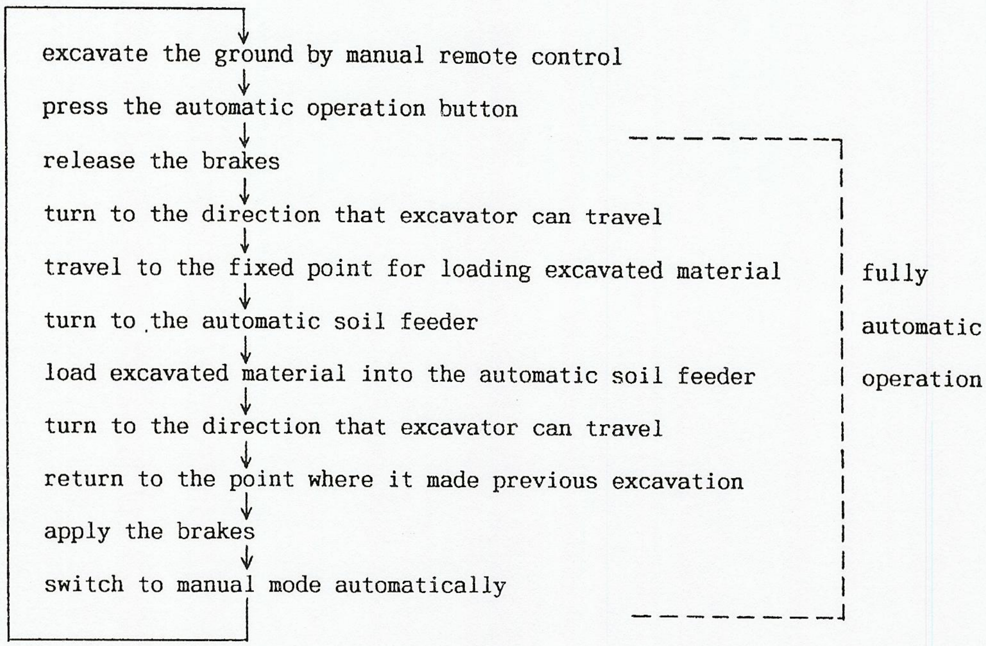

Fig. 3 Diagram of automatic operation

Automatic operation is controlled by sequence program. The sequent order, speed and stopping point were input prior to operation.

2) Realtime monitoring system of excavator's movement

On a real-time basis, it is indicated in the control room how the excavator moves in the pressurized site. Various sensors are equipped on the excavator, and transmits data regarding the excavator's position and posture to the personal computer, which is set in the control room and analyzes, calculates and indicates graphically. As the data processing time is 0.25 second, the movement of excavator on the computer-display can be seen without feeling the delay of time.

Monitoring display is shown in Fig. 4.

3) Measuring system of excavating progress

Information of the excavating progress of cutting-edge is most important for the caisson's sinking and settlement control. In this system, for the purpose of measuring the configuration of cutting-edge part, 4 ultrasonic-sensors are attached to the excavator. When an operator presses a button, the excavator automatically travels along the cutting-edge and continuously measures the distance between the excavator and digged ground surface.(Fig. 5) In proportion with the change of pressure and temperature in the work chamber, the measured value is corrected by a standard sensor's value which is defined by measuring the fixed distance, i.e., 1 m.

As shown in Fig. 6, it indicates the display of excavating progress, by the development and cross section charts.

These three systems and hand-operated system are in correlation with each other. Their general diagram is shown in Fig. 7.

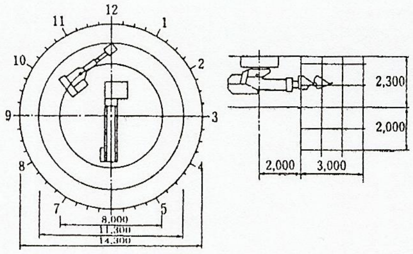

Fig. 4 Display of "Realtime monitoring system of excavator's movement"

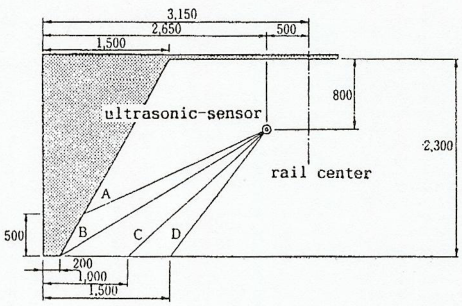

Fig. 5 Plan of measuring system

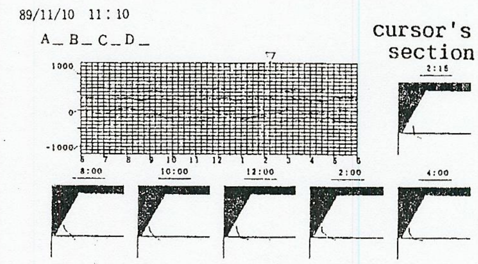

Fig. 6 Display of "Measuring system of excavating progress"

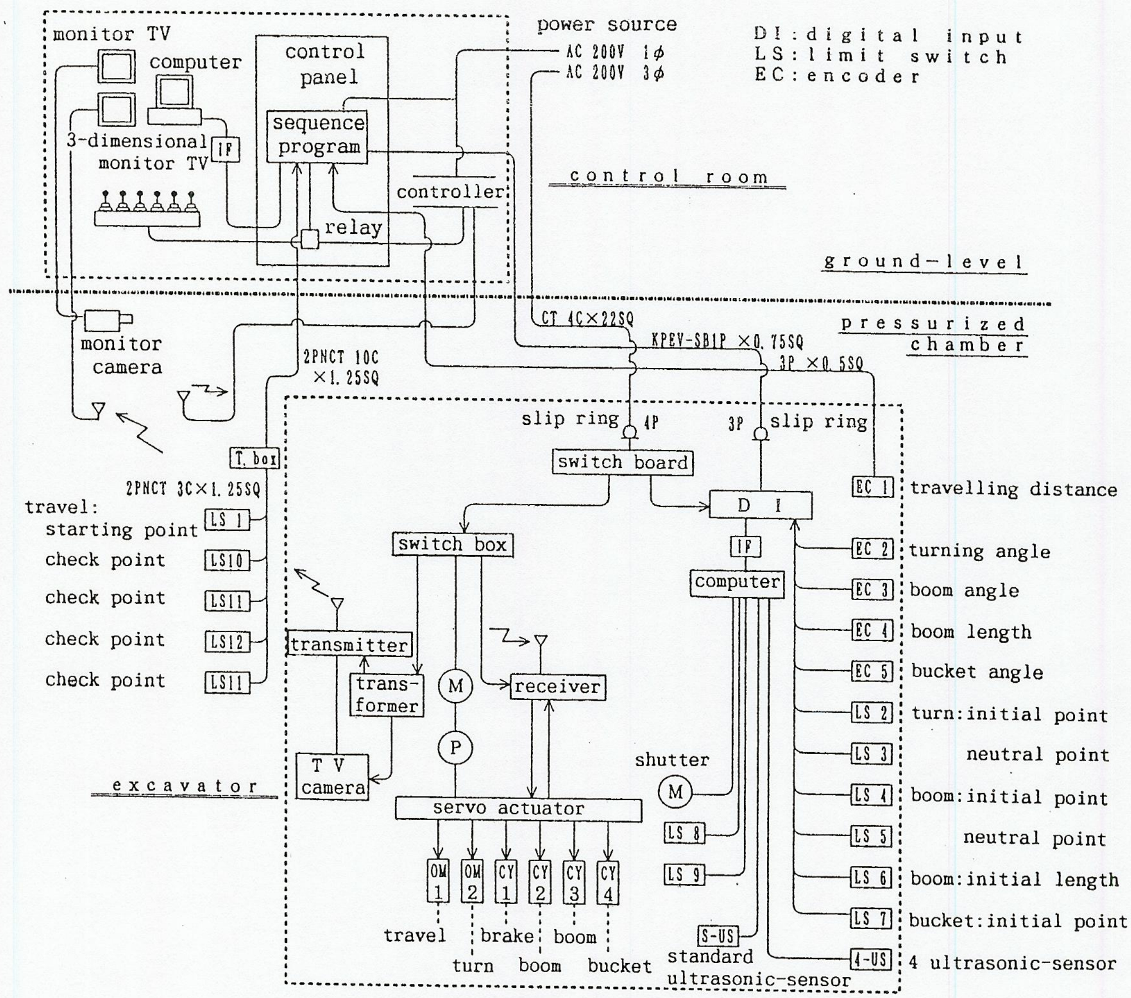

Fig. 7 General diagram of three systems

3. Application

This system has been used at the construction site of the shield tunnel departure shaft. This work, Tokyo Electric Power Co., Inc., Construction of Gas Supply Conduit Between Futtsu and Sodegaura (Work Section No.4), Shield Tunnel Construction Across Kisarazu Harbor, is to lay gas pipe lines in total distance of about 25 km. This work section is the under sea bed crossing part including 2 shield departure shafts. First shaft had been executed from August 1989 to January 1990, and good result was obtained by using this system. Now this system will be applied to the second shaft from January to July 1990 successively.

Table 1 shows shaft scales, Photo 1 shows equipment in the control room located at ground level, and Photo 2 shows mechanical equipment in the pressurized chamber.

In this case, when the pressure of working chamber was less than 1 kg/cm^2, an operator worked in the pressurized chamber. But when the pressure became more than 1 kg/cm^2, this system was applied.

In this system, the mechanical equipment can be operated from both the pressurized chamber and the ground-level control room.

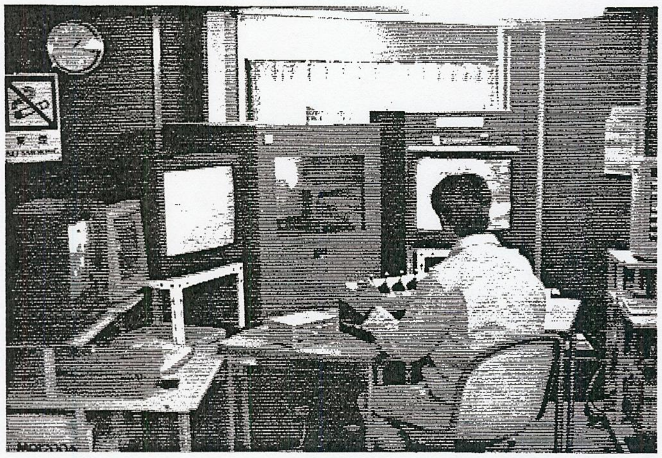

Photo 1 Control room located at ground-level

Table 1 Scale of shield departure shaft

No. 1 shaft	
internal diameter height thickness of wall	12 m 25.9 m 1.1 m
No. 2 shaft	
internal diameter height thickness of wall	12 m 28.6 m 1.3 m

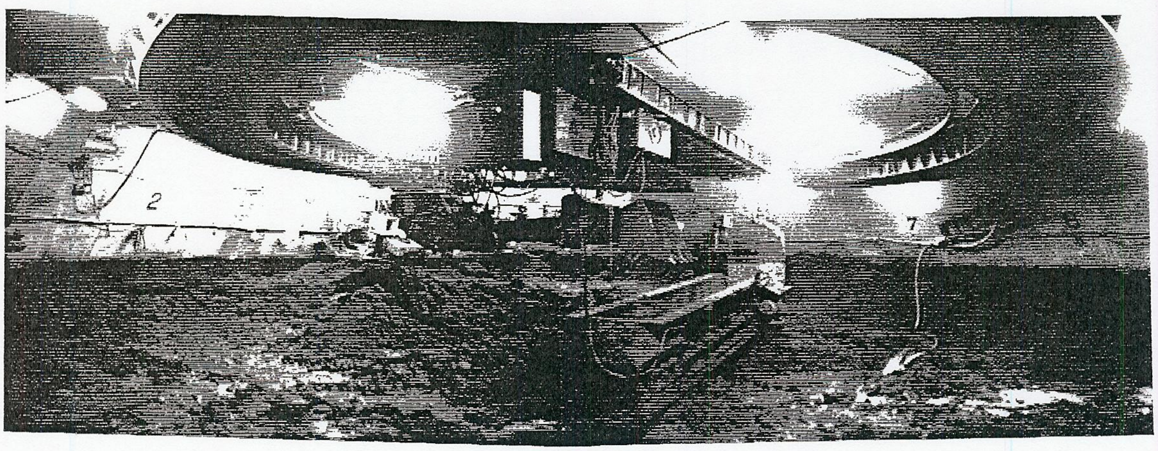

Photo 2 Pressurized work chamber

3-1. Remote control and automatic operation

When the operator started to excavate the ground, he operated the excavator by manual remote control using TV camera and "Realtime monitoring system". And when he wanted to load excavated material into the soil feeder, he applied "Full automatic operation system". The excavator loaded 4 or 5 times, and about 1 m^3 sediment was stocked on the soil feeder. Then, operating the soil feeder automatically, he put the excavated material into the earth bucket. As the case may be, he could operate the soil feeder by manual remote control. A worker who was assigned to the material lock, operated winding up of the earth bucket, so the operator in the control room signaled him to wind up the earth bucket. After that, the operater confirmed that the soil feeder returned to the prior position, and continued the excavating work.

Repeating this process, the caisson was sunk and settled.

3-2. Observational monitoring and measuring system

Another measuring system was used, which controlled the sinking and settlement conditions of the caisson itself, besides "Realtime monitoring system" and "Measuring system". It measured and displayed the caisson's inclination, depth of sinking, pressure of working chamber, and the effect which the construction work had on surrounding environment. Various gauges were equipped in caisson inself and surrounding ground, and measured continuously. The display of "Sinking and settlement control system" is shown in Fig. 8.

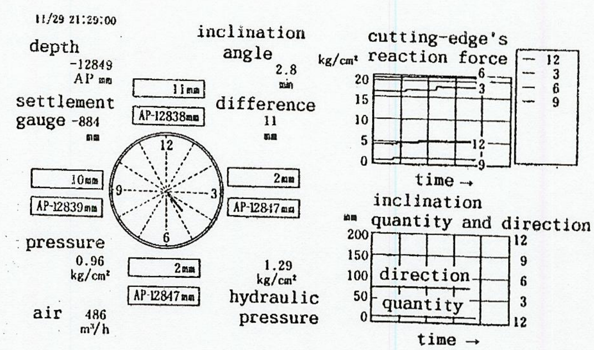

Fig. 8 Display of "Sinking and settlement control system"

4. Application results

4-1. Excavator remote control

At first, as the operator was inexperienced and unskilled, he seemed to be puzzled at the manual remote control. But, as he got accustomed to the new operation system by training, working efficiency increased to a level as expected at the beginning, i.e., 4 m^3 an hour on average.

4-2. Automatic operation

It was confirmed that the automatic operation was very effective beyond expectation. Firstly, there was no collision between the excavator and other equipment or caisson itself. Secondly, the operator could load excavated material soundly and surely. Lastly, construction work was executed safely and securely, because the operator was free from not only non-essential and repetitive work but from complicated operation, so the operator's burden was greatly relieved.

4-3. Observational monitoring and measuring system

When the operator was required to make various judgements , for example, to check the excavator's collision or to decide the excavating place for correcting the caisson's inclination, aforementioned three systems offered him very useful information. It was confirmed that each of three systems was not only indispensable but also sufficient when the remote control system was to be applied from the ground level.

5. Future plans

This system shall be applied to the caisson which can be excavated by one or two excavators and which depth is within 50 - 60m. But the system has to be changed if the caisson scale and depth are different from the aforementioned case. So it is necessary to conduct research of the Ground-Level Remote Control System for Pneumatic Caisson which scale is greater and deeper.

Future plans are as follows:

1) Automatic operation of carrying excavated material

This problem was not solved this time. As the efficiency of carrying the excavated material out determines the efficiency of the total caisson construction, especially in the great depth caisson, the development of the consecutive carrying system or full automation system using the bucket is necessary.

2) High grade monitoring and measuring method

This time, 4 TV cameras were used in total, together with the newly developed techniques, "Realtime monitoring system", "Measuring system". But each of them has some merits and demerits. Thus successive research is necessary from standpoint of high grade monitoring and measuring system in place of man's eyesight.

3) Repairing method of mechanical equipment in the pressurized chamber

When the excavator broke down, the causes were first inferred by using TV monitors. Then a worker went into the pressurized chamber and made repairs. But the time it took to repair was different, case by case, from dozens of minutes to a few hours, according to the broken place and grade of damage. To execute the great depth caisson construction, it is necessary to study the repairing method which will minimize the repairing time for a worker to be in the pressurized room.

6. Conclusion

By controlling the Pneumatic Caisson work with the foregoing systems, the operation in the pressurized chamber was greatly reduced, and the environmental and safety problems were solved. Moreover, controlling every site work from the control room, and reflecting necessary information to operation on a real-time basis, sinking and settlement work was executed precisely and securely.

Furthermore, a tremendous progress was made towards the construction of great depth caisson, through the completion of this Remote-Control System. But it must be realized that this system is only the first step towards Full Automatic or Robotic Operation System. So, It is necessary for the authors to make continuous research into this system henceforth.