A REMOTE-CONTROL SYSTEM IN THE PNEUMATIC CAISSON METHOD

Koichi Fujita, Dr. Eng.

General Manager, Civil Engineering Division,
Shiraishi Corp., Japan
E-mail:fujita-k@shiraishi.com

Abstract: A remote-control system in the pneumatic caisson method has been developed to control from the ground surface all the operations related to excavation and caisson sinking, thus minimizing workers' exposure to compressed air environment. The entire system consists of a remote-control operation system and a centralized control system on the ground surface that enable unmanned mechanical excavation in compressed air and an automatic operation system of caisson shovel. It increases accuracy of sinking in building pneumatic caisson of high quality, reduces manpower and ensures safe working environment.

Keywords: Pneumatic caisson, caisson shovel, remote control, automation, shortening contruction period, working environment

1. INTRODUCTION

The pneumatic caisson method has a history of over 150 years since its inception. As its distinctive features, it is able to deal with change in geological feature and permits identification of caisson's bearing layer by the eye. Ever since it was imported into Japan, the method has undergone unique improvement and development in this country through a number of field application. Manual excavation, among others, was replaced first by manned mechanical excavation and then by remote-control mechanical excavation. The latter has been replaced by automatic excavation in an effort to increase productivity. In addition, unmanned pneumatic caisson method combined with the helium-gas mixed air respiratory system provides substantially improved working enviroment and has made it possible to build very deep underground structure.

2. PAST RECORDS

2.1 Large caissons

There are about 50 caissons completed with bottom area exceeding 1,000 m2 in Japan. Table 1 shows the 10 caissons of the biggest bottom area ever placed. The biggest among them was built for the two anchorages of Rainbow Bridge.

Table 1. Large Caissons

2.2 Deep caissons

Most caissons have been placed at the depth ranging from 10 m to 40 m below the ground surface. As shown in Table 2, the deepest caisson built todate is for the work shaft for a water pipeline in Osaka that was sunk to 63.519 m below the ground surface.

2.3 Caissons built in highly compressed air

As shown in Table 3, the caisson built in the highest compressed air so far is for a water intake tower at Otairanuma lake at 0.529MPa. For construction of caisson in highly compressed air, an auxiliary method is generally employed at the same time to improve and maintain working environment. Even though it depends upon their individuality or physical condition, workers tend to show nitrogen narcosis in compressed air at around 0.294 MPa, and present preliminary symptom of oxigen toxicosis at 0.392 MPa. As working time is limited under such highly compressed air environment, a variety of auxiliary methods are often employed concurrenly.

3. UNMANNED CAISSON METHOD

3.1 Remote-control operation system

The excavation and discharging of excavated materials used to depend upon manpower in a cramp

Project	Dimension (m)	Depth(m)	Year completed
Anchorage of Rainbow Bridge	70.1x45.1	46.5	Apr., 1990
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Niigata Thermal Power Plant	59.0x36.0	13.0	Feb., 1962
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Ventilation Tower of Tokyo Coastal Road Tunnel	45.0x45.0	26.9	Dec., 1997
Ventilation Tower of Tokyo Coastal Road Tunnel	45.0x45.0	26.0	Dec., 1997
Pumping Building of Otagawa Sewer Treatment Plant	48.2x37.3	27.1	Mar., 1980
Ichikawa Sewer Pumping Plant	52.6x32.1	29.0	Jan., 1984
Main Tower of Tsubasashi Bridge	40.1x40.1	33.0	Oct., 1990
Main Tower of Tsubasashi Bridge	40.1x40.1	28.0	Aug., 1990

Table2. Deep Caissons

Project	Depth (m)	Air compression (MPa)	Year completed
Kunijima Water Pipeline Shaft	63.5	0.539	Nov., 2000 (scheduled)
Ogijima Blast Furnace Foundation	56.3	0.294	Sept., 1975
Main Tower of Ktushika Harp Bridge	56.2	0.363	Nov., 1983
Main Tower of Meiko Chuo Ohashi Bridge	52.5	0.294	Mar., 1993
Sakaebashi Power Cable Line Shaft	52.5	0.392	Oct., 1989
Takasago Water Pipeline Shaft	51.5	0.441	June, 2000
Ajigawa Water Gate Substructure	51.5	0.314	May, 1969
Ajigawa Water Gate Substructure	51.3	0.314	Apr., 1969
Ajigawa Water Gate Substructure	51.3	0.314	Apr., 1969
Kitachiba Water Pipeline Shaft	49.4	0.314	May, 1985

Table3. Caissons built in highly compressed air

Project	Air compression (MPa)	Depth (m)	Year completed
Kunijima Water Pipeline Shaft	0.539	63.5	Nov., 2000 (scheduled)
Water Intake Tower in Otairanuma Lake	0.529	45.4	Mar., 1970
Takasago Water Pipeline Shaft	0.441	51.5	June, 2000
Shin Moritsubashi Bridge	0.436	45.0	Oct., 1982
Inabegawabashi Bridge P1	0.421	43.0	May, 1998
Inabegawabashi Bridge P2	0.421	43.0	May, 1998
Inabegawabashi Bridge P3	0.421	43.0	May, 1998
Mikawashima Sewer Main Shaft	0.412	47.2	Nov., 1993
Nasagawa Bridge	0.402	42.0	Sept., 1976
Sakaebashi Power Cable Line Shaft	0.392	52.5	Oct., 1989

compressed-air environment, as shown in Photo 1.

The shift from manpower to mechanization for excavation in the working chamber dates back to the time when the electrically powered excavator was developed in the mid 1960s. This was replaced by the caisson shovel travelling on the ceiling of the working chamber in the early 1970s. The latter features better mobility and productivity, as compared with the former, and is in general use at present.

Figure 1. Remote-control operation of shovel

The remote-control operation system being frequently applied today is a combination of the remote-control caisson shovel and the automated loading system for discharging excavated materials that are controlled at the centralized control room on the ground surface.

At the initial stage of its development, the caisson shovel was operated by remote control at a capsule under atmospheric pressure resting on the ceiling slab of the working chamber, as shown on Figure 1. The capsule was of free rotary type, permitting

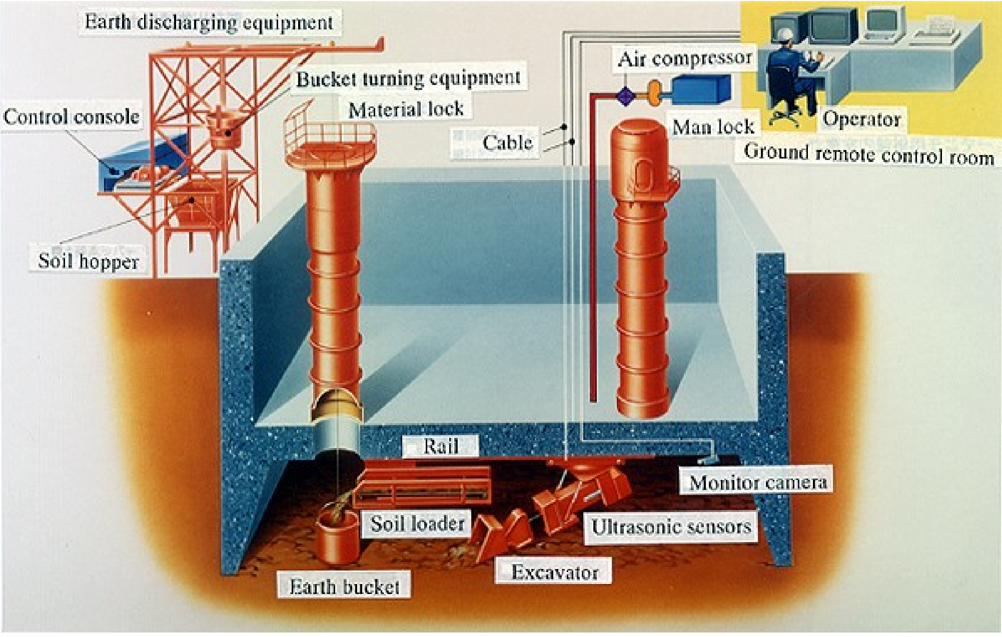


Photo 1.

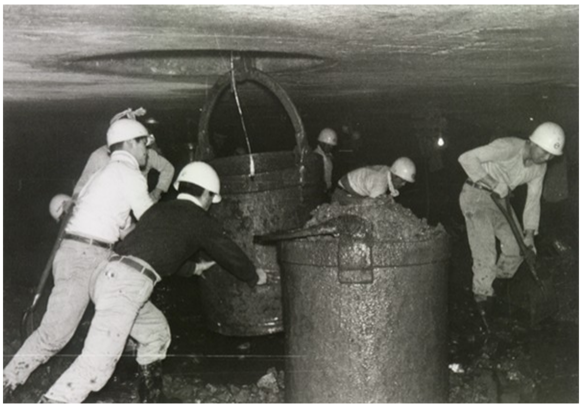


Photo 2.

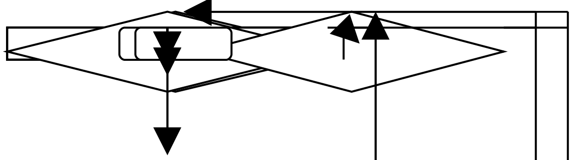
operation of the caisson shovel through the capsule's observation port.

The caisson shovel, as it appears in the right side in Photo 2, is an excavation equipment tavelling on the railing installed on the ceiling slab of the working chamber and operated by remote control at the centralized control room on the ground surface. The automated loading system, as it appears in the left side, consists of an electrically powered belt conveyor movable in both vertical and horizontal directions, and conveys excavated soils unloaded from the caisson shovel right into the soil bin at a fixed volume. Productivity in excavation and discharging of excavated materials has been increased substantially thanks to this system, as excavation can be continued without interruption at the time when the bin is lifted for discharge off from the working chamber.

All the information required to control excavation and caisson's sinking is collected at the centralized control room on the ground surface, so that operators may exercise control over a series of mechanical movements covering from excavation to discharging process through TV monitors, as shown on Photo 3.

Photo 3.

The system was employed for the first time at the construction site of Meiko Nishi Bridge built by Japan Highway Corporation. Ever since, more than



50 caissons have been built with the use of the system.

3.2 Automatic operation system

It is not trouble-free to operate remote-control equipment including the caisson shovel in a cramp working chamber via a TV camera installed in a working chamber. It is difficult to determine exact position and attitude of the caisson shovel and know conditions of excavated face precisely, and, in addition, other equipment in the working chamber often remains to be obstructive for the efficient operation of the shovel, lowering productivity. To solve the problem, repetitive movement of the shovel is automated in this system, except for the movement to negotiate change in ground strength. As the system's flow chart shows in Figure 2, a series of mechanical movements generated by operator's remote control are transmitted as signals to the shovel via a drive control mechanism and memorized at the memory unit. Mechanical movement is thus repeated automatically to reflect the same pattern as memorized until the pattern is modified to suit caisson's behavior and change in ground strength. This system shows its advantage at loading movement requiring meticulous care in a cramp working chamber and repetitive movement of the same pattern. More than 10 caissons have been completed todate with this system.

Figure 2. Automatic shovel operation system

Start

Remote-control operation

Signal control

Shovel movement

Memorization

Automation No

Yes
Automatic operation

End of operation No

Change in condition
Yes No
Yes

End

4. HELIUM GAS MIXED AIR RESPIRATORY SYSTEM

Development of the unmanned caisson method has relieved workers of compressed air work, except for servicing to excavation equipment and removal of obstruction in the working chamber. It is generally said that the air compression limit permissible for man's safe operation is at around 0.392 MPa or 4kgf/cm2. Physical disorders like nitrogen narcosis, oxigen toxicosis, respiratory distress etc. appear as air compression increases. The bends, or caisson diesease tends to occur at the stage when human body undergoes change from decompression to atmospheric pressure. In an effort to prevent occurrence of such a physical disorder, a helium gas mixed air respiratory system has been developed. This system provides the worker with safe working environment even in higher compressed air when caisson is sunk to deeper position. In this system, excessive amount of nitrogen and oxigen causing physical disorder are replaced as much with helium gas. This theory was adopted in the pneumatic caisson for the first time in Japan even though it had been known in the field of the deep-sea diving since long and applied to the depth of 300 m in Europe and U.S.A.

Following animal testing, medical and technical verification in compressed air at 0.686 MPa, experimental testing and training, this system was adopted for the first time in the construction of Meiko Nishi Bridge Phase II implemented by Japan Highway Corporation in 1995. However, use of the system was then limited in scope; workers used the system only in servicing to equipment in the working chamber in highly compressed air. The maximum air compression reached 0.358 MPa without causing hyperbaric disorder at all. Nonetheless, this was a great success. Photo 4 shows servicing to excavation equipment in highly compressed air with the aid of the system.

Photo 4.

The working chamber beneath the caisson is filled with compressed air compatible with groundwater pressure working around the caisson, and the mixed gas is supplied from the ground surface to the working chamber through piping. Workers breathe the mixed gas, wearing masks on their face. Photo 5 presents operation scene at the centralized control room installed on the ground surface. At this room, control activities related to working environment are also performed, like adjustment to pressure difference between compressed air and respiratory mixed gas and control of decompression process.

Photo 5.

Todate, unmanned caissons incorporating the respiratory system have been built for five bridge piers and two work shafts in this country.

5. FUTURE TASKS AND PROSPECT

The pneumatic caisson method was once reputed for poor working environment, limited working time, labour-intensiveness, execution limited in depth, etc. However, with introduction of unmanned caisson excavation system, automated operation system and helium-gas mixed air respiratory system, the prejudicial view against the method has been completely eliminated. As our future tasks, completely unmanned method is yet to be developed, and the automatic operation system needs further improvement to deal with complexity of ground conditions and caisson's behavior.

Our efforts will continue to be forcused upon technological development of fully automatic and labour-saving system so that the pneumatic caisson method may be established as an integral method in the field of deep underground construction technology.

6. CLOSING

There is no denying that development and improvement in the construction technology including unmanned automatic caisson method will be furthered in the future to come. Such a move will bring substancial change to the scope of work to be performed by those who work on construction sites, and engineers will be asked more increasingly to assume major roles in supporting the technological development and making the best use of the same in construction projects. It is for this reason that it is all the more essential to train engineers so that they may be able to keep abreast of technological development like mechanization and robotization.

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