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Prospects for Applying Automation/Robotization of Underwater Foundation Work

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ABSTRACT

In recent years, major marine engineering works have had to be executed in deep waters with severe waves far out at sea, while there has been increased demand for improved construction efficiency, accuracy, safety, and economy.

In this paper, underwater foundation work at great depths and in soft ground is considered as one of the technologies in marine civil engineering work, and an attempt is made to examine its automation and robotization. The examination covers marine survey robots, deep-water mixing robots for ground improvement, and rubble mound leveling robots.

The problems existing under present conditions are examined along with themes that need be tackled in the future. "Near future" designs for each robot type mentioned above are presented and in addition, "future shape." By considering such future shape, as shown in Fig. 1 for example, the action required now can be made clearer.

1. PRESENT LEVEL OF AUTOMATION/ROBOTIZATION

1.1 Present Status of Underwater Foundation Work and Future Prospects

(1) Deep-seated mixing treatment method

In the deep-seated mixing treatment method, soft ground is chemically consolidated using a consolidation agent, such as cement slurry. The method has been in practical use since 1975. Since then, more than 21 barges for doing this work have been constructed and the volume of soft soil processed has reached a total of about 7.95 million m^3 (as of March 1988).

This treatment has significant advantages:

1) High strength can be obtained in a short period of time;
2) Relatively little impact on the peripheral environment;
3) Concerns about soil discharges are for lower than in the case of the displacement method, etc.

The procedure for the deep-seated mixing treatment method is shown in Fig. 2. Against the background of improving electronics technology in recent years, automation/robotization has been introduced into various phases of construction and construction management. However, the level of automation is not consistent and the situation is such that there are only a few cases of wholly unmanned construction. This is mainly because there are many outstanding problems coping with site conditions which exhibit complex variations, such as meteorological, marine, and ground conditions.

In order to realize full automation/robotization of the deep-seated mixing treatment method many technical issues still have to be resolved as state-of-the-art technology moves forward, but we anticipate that different modes of construction will emerge thanks to the strides being made in the technology of robotization. These will include:

1) Unmanned construction;
2) Automation of quality control;
3) Ground improvement to great depths in extremely deep water.

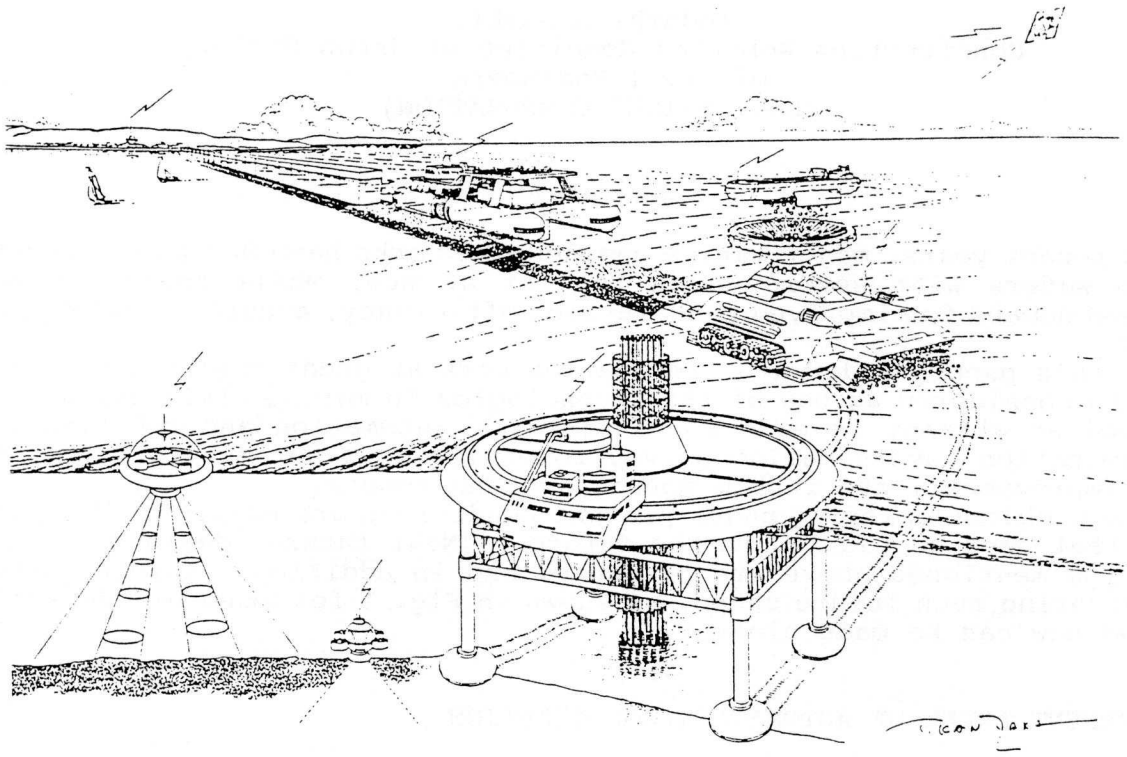


Fig. 1 Future image of underwater foundation work

(2) Rubble mound leveling method

The preparation of rubble mounds for foundations is conventionally performed by rough leveling, slope leveling, and formal leveling. A diver finishes the mound to the designated accuracy. Although the size of rubble to be levelled differs according to the area and the structure, generally each piece weighs several kilograms to 200 kilograms. The accuracy of the levelled surface has to be $\pm$5 cm according to the Common Specifications for Harbor Work. This is, therefore, a very difficult operation that calls for extremely high accuracy in the placing of relatively large rubble.

With regard to mechanization of this difficult rubble mound leveling operation, large-scale experiments have been continued since the latter half of 1965.

Initially, machines were selected for possible use in the process: horizontal force (horizontal vibration) leveling machines, underwater bulldozers, vertical force (weight) leveling machines, rotary power (screw) leveling machines, etc.

Subsequently, the development of mechanized methods for rubble mound leveling became a job tackled not only by governmental organizations, but also by the private sector, and various leveling machines were announced. Of these, some have already been used in actual construction work.

The automation-robotization of rubble mound leveling has reached the stage where the prospect of putting it to practical use at about -30 m is possible at present. Even so, the operation has to be carried out in water where the condition of the construction can be difficult to grasp and in adverse conditions --- such as the need for waterproofing and corrosion prevention, the problem or water pressure, poor visibility, and flow pressure.

With the aim of applying the method to deep sea areas in the future, there is hope that an extremely durable robot able to level large rubble with high accuracy and with good operability will be realized.

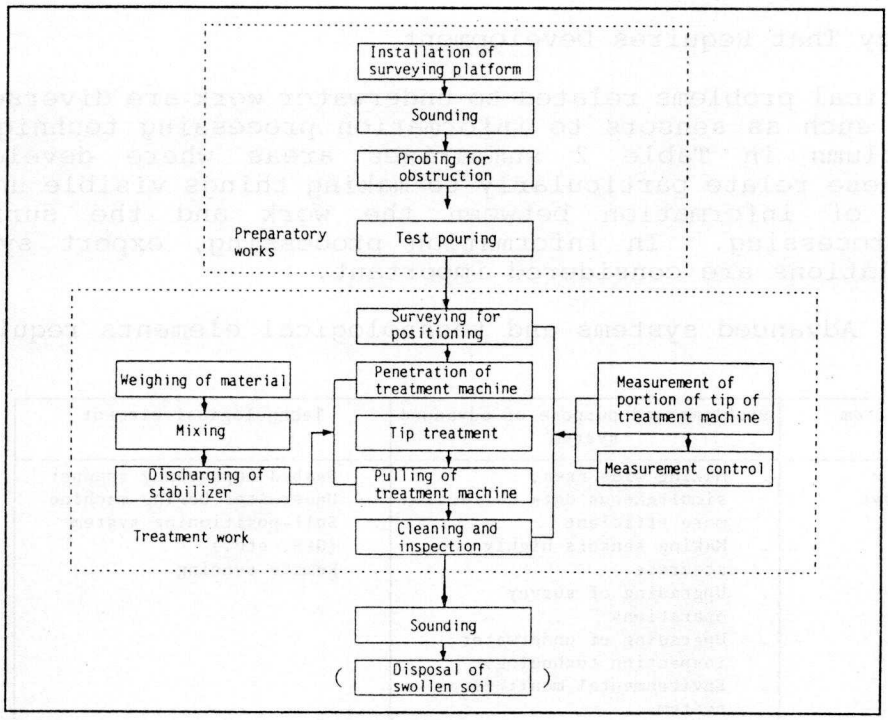


Fig. 2 Construction procedure for deep-seated mixing treatment method

1.2 Future Problems in Underwater Foundation Work

This section constitutes a survey of existing technology for the deep seated mixing treatment method and for rubble mound leveling, and summarizes the pressing problems which need to be overcome to achieve greater automation/robotization.

This is considered that progress in the automation of the deep-seated mixing treatment method is slightly better, so promotion of robotization may be expected in the near future. On the other hand, the level of automation in rubble mound leveling is generally lower, and various problems needing future examination have been pointed out.

Table 1 Technical problems in underwater foundation work

	Technical problems common to all underwater work	Technical problems involved in individual methods
Deep-seated mixing treatment method	1 Sounding and probing for obstructions 2 Unmanned construction . Positioning of work barge . Actual implementation . Cleaning and inspection	1 Grasping of natural conditions and establishment of environmental monitoring system 2 Establishment of surveying system 3 Development of underwater inspection technology 4 Problems a robot faces in coping with the underwater environment
Rubble mound leveling method	3 Automation of quality control 4 Automation of materials conveying	1 Systematization of rubble transport 2 Automation of management of dumped quantity of rubble 3 Automation of leveling of rubble mound 4 Establishment of leveling accuracy

Table 1 summarizes the common technical problems and those specific to each process.

2. PROPOSAL FOR ADVANCED SYSTEM

2.1 Technology That Requires Development

The technical problems related to underwater work are diverse, ranging from elements such as sensors to information processing techniques. The right-hand column in Table 2 summarizes areas where development is necessary. These relate particularly to making things visible underwater, communication of information between the work and the surface, and information processing. In information processing, expert systems and analysis simulations are considered important.

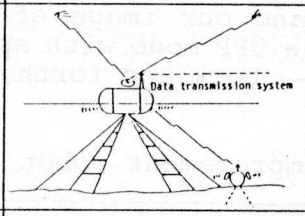
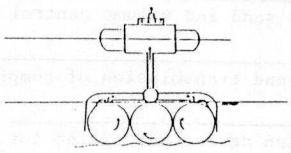
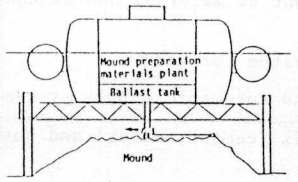
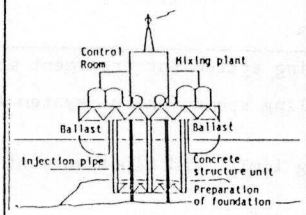
Table 2 Advanced systems and technological elements required

Item	Problems and purpose of advanced system	Technological element
Marine surveys	. Making wide-area, simultaneous data collection more efficient . Making sensors highly accurate . Upgrading of survey operations . Upgrading of underwater inspection technology . Environmental monitoring system	. Seabed topography scanner . Underwater boring machine . Self-positioning system (GPS, etc.) . Remote sensing
Planning/ design	. Improving the accuracy and efficiency of design . Readiness of feedback from construction to design	. Upgrading of information processing . Establishment of simulation technology . Automatic design system . AI
Construction	. Reduction of operations at site and underwater . Unitizing of structures	. Seabed boring machine . Systematized construction barge . Automatic positioning system . Robot for underwater monitoring
Construction management	. Reduction of uncertainties at the construction stage	. Expert system . Information network data processing
Inspections	. Reduction of dangerous, skilled operations . Upgrading of accuracy of inspection data	. Underwater monitoring robot . Inspection of steel members for corrosion . Concrete quality inspections
Maintenance	. Upgrading of maintenance management . Making repair work more efficient	. Repair robot of remote-control type . Underwater painting

2.2 Proposal for Advanced System

A future survey robot, ground improvement robot, rubble mound leveling robot, and multi-function robot for construction are proposed in Table 3. These robots form a complete advanced system, covering surveys to maintenance.

Table 3 Outline of advanced system

	Conceptual drawing	Specific details of automation/robotization	Specific technologies required
Survey robot		. Making wide-area data collection more efficient, simultaneous, and more accurate	. Improved accuracy and discrimination in underwater inspection . Improved determination of R and automatic positioning technology
Ground improvement robot		. Higher accuracy measurement functions and ground improvement functions . Fully automatic control by expert system	. Development of robot for detection and recovery of obstructions . Surveying, quality control, and core sampling
Rubble mound leveling robot		. Fully automatic leveling machine with both supply and leveling functions manages finishing of the rubble mound in real time	. High-accuracy rubble dumping control system linked to barge positioning system . Dumping rate measurement and drawing control system
Multi-functional robot for construction of structure		. Multi-function robot that performs foundation ground treatment, installation of structures, mound treatment, filling, and all operations between structural work	. Underwater maintenance and control technology . Inspection technology offering quality and accuracy underwater

3. TECHNICAL PROBLEMS CONFRONTING THE ADVANCED SYSTEM AND SOLUTIONS

3.1 Survey Robot

Most underwater survey robots currently in use are of the floating type, and their position and direction cannot be maintained accurately when there are currents. This results in various restrictions on surveying and measurement operations. Measures to cope with this problem are an issue for the future.

Also, it is necessary to give a future survey robot certain functions, including those listed below.

Visual function
Manipulator function
Underwater position indicator function
Propulsion function
Measurement function
Communication function

Of these, future improvements are greatly needed to the visual, measurement, and communication functions. It is also desirable that systems linking underwater and surface equipment, and the on-shore station, be improved. Ideally, a real-time remote control system based on bi-directional communication will be developed.

3.2 Ground Improvement Robot

The near-future image for a ground improvement robot (beginning of the 21st century) is the unmanned operation of about 30 m in water depth and improvement thickness of about 50 m. Table 4 indicates some of the problems with current ground improvement systems, and our image of a near future robot which automates these systems. It is a CEP mode with speed; the self-propelled robot moves in four directions --- back and forth, and right and left --- in a measuring-worm manner.

Table 4 Problems in developing a ground improvement robot (by operation)

Operation	Problem
Spreading of sand	1 Pressurized pumping method for sand and volume control system
Positioning	2 Method of confirming position and transmission of completion signal
Material supply	3 Automatic pipe (hose) connection device and system for supply from the cement transport barge to silo 4 Confirmation of remaining amount of material and automatic supply volume control system 5 Automatic supply device and system for sand 6 Residual seawater detection and automatic supply system
Production of slurry and supply	7 Automatic weighing of materials (cement, water) and automatic production system 8 Automatic detection and supply system for remaining volume in agitator 9 Automatic slurry supply system
Improvement operations	10 Automatic moving and positioning system for treatment machine 11 Automatic penetrating and pulling speed control system for machine 12 Automatic penetration, pouring limit, and tip treatment control system for treatment machine 13 Automatic control system for number of revolutions and torque of treatment machine 14 Automatic cleaning and abnormality confirmation system for agitator blade in treatment machine
Treatment and disposal of swollen soil	15 Automatic detection system for treatment volume 16 Automatic treatment system
Movement within construction area	17 Movement start detection system 18 Automatic movement and confirmation of position system
Water quality survey	19 Seawater pollution, contamination detection system, and control limit alarm system
Future	20 Satellite measurement/positioning system

In the future, when the siting of structures at sea evolves further, the function of robots will change considerably due to the differing conditions, such as deep water and high waves.

The functions of the robot will be divided; a seabed robot will perform underwater operations while the plant and central control room will be on the surface.

Installed above the surface will be a slurry plant including cement silo, a sand storage tank, a central control room (usually unmanned), a satellite reception/transmission dish for communications between the central control room on shore and the seabed robot, etc.

Although the seabed robot is self-propelled, and can therefore move freely on the seabed, its motion is controlled by following its position through communication between the work barge and satellite and by orders from the control room on the barge. Quality control during construction work is carried out automatically. Together with information on water pollution, data are transmitted to the central control room on shore where they are recorded. The seabed robot moves in unmanned operation in synchrony with the work barge.

In this way, ground improvement, which depended largely upon manual labor conventionally, will be improved in accuracy and quality through robotization. Having achieved a reduction in scatter in this way, the allowable stress, quality control standards, safety factor, etc., which were determined on the basis of conventional design, will be reconsidered and improved.

3.3 Foundation Mound Preparation Robot

The near-future model of a foundation mound preparation robot (early 21st century) assumes operation 10-20 km off shore and in water depths of about 30-50 m.

The functions required of a foundation mound preparation robot include the following:

(1) Detection of position
(2) Detection of geology
(3) Movement
(4) Leveling
(5) Quality control
(6) Mound configuration control

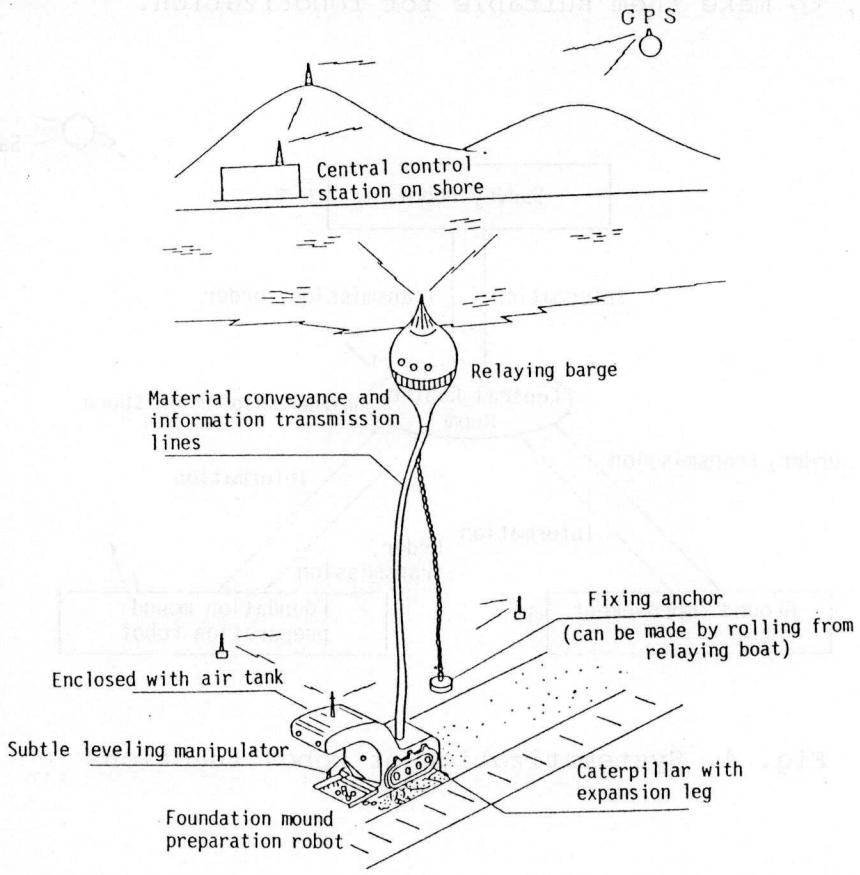


Fig. 3 Outline of future foundation mound preparation robot

Naturally, improved function and accuracy is necessary, but it is also considered important to examine how the functions are combined and systematization of the whole process. In addition, robotization should also be examined from an entirely different angle. Figure 3 shows the outline of a future foundation mound preparation robot.

The problems related to this system as regards future robotization are as follows.

(1) Upgrading all functions by linking the function of individual robots.

(2) Improvement by relaying barge that tends to be affected by natural conditions.

(3) Assured construction management when work is far out to sea and at great depth.

(4) Support structure in case of an emergency such as a robot malfunction.

It is also considered important to work on design and construction in directions that will readily yield progress with robotization, and some measures for doing this are enumerated below:

(1) Standardizing mound configurations (top width, mound thickness, slops, etc.) to make them suitable for robotization through standard operations.

(2) Establishing efficient leveling accuracy in conformity with the capability of the robot.

(3) Proceeding with the standardization of rubble or the development of new materials suitable for robot handling.

(4) Rationalizing the design method of structures as a whole, and not just the mound, to make them suitable for robotization.

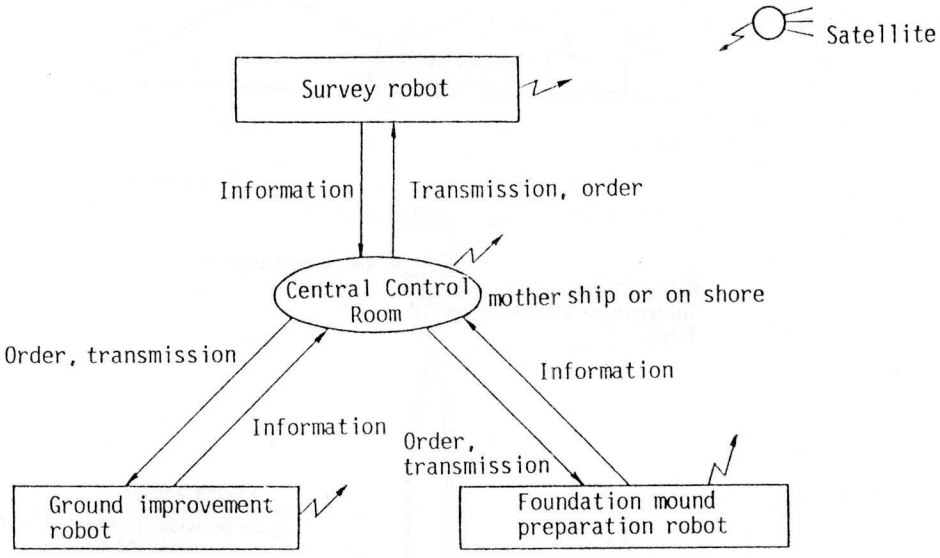


Fig. 4 Systematization of robot functions

4. CONCLUSION

As described in this report, marine construction is subject to many adverse condition; its operations are broad in scope, the working environment is severe, etc. Compared with other fields, this makes it a very difficult domain for the introduction of automation/robotization. From a different angle, however, it can be said that the expectations of automation/robotization are far greater.

This paper has specifically examined three types of robot; survey robots, ground improvement robots, and foundation mound preparation robots as specific robot.

If construction is carried out from the water's surface where it is readily affected by waves, the advantages of advanced systems cannot be fully exploited for reasons of operation rate and safety. Consequently, the establishment of a construction system based on seabed construction or underwater construction will become an important issue. This will give seabed movement technology, underwater position control, underwater information transmission systems, etc., priority in the development of technology in the future.

To further accelerate robotization, the need to reconsider which design and construction methods are suitable for robotization was mentioned, and some examples were given. At the same time, it is important to systematize robot functions. Figure 4 shows a system in which each robot is functionally linked for the control of mutual information.

Individual robots are controlled from the Central Control Room (on the mother ship or a shore), where information from each robot is collected and analyzed. An information processing system systematizes the data and orders the next operation in real time while also supplying information to the other robots. Also, checks on the completion of operations and a method of coping with emergencies, as well as control of quality and completed form, can be implemented at the same time. Based on this, corrections to subsequent operations can take place continuously.

The big problem of the future appears to be the functionality of each robot and the creation of a comprehensive system which operates efficiently as a whole.

The proposals made in this paper are the results of the study performed by the Subcommittee of the Construction Robotic Committee, Japan Society of Civil Engineers. The names of the people who participated in this study are as follows.

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