The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

DEVELOPMENT OF A COMPUTER AIDED CONSTRUCTION SYSTEM FOR SUBMARINE EXCAVATION WORKS

Motoh Tsunoda, Masaki Hirano, Hiroaki Inoue, Masahiro Harada
Kumagai Gumi Co., Ltd, 2-1 Tsukudo-cho, Shinjuku-ku, Tokyo 162, Japan

ABSTRACT

For the submarine excavation of the anchorage foundation for the Kurushima Bridge connecting Honshu and Shikoku, a computer aided construction system was set up and used to strictly control all the construction processes, including the submarine topography survey prior to excavation, routine excavation, finish and confirmation of the excavated sea bed. The result was savings in time and manpower, and improvement in quality.
High quality control of construction was achieved.

In this paper we will introduce the computer aided construction system that was developed for the above project. At the same time, we will report on research into computer aided construction, which has shown great promise as a new construction method for marine projects.

1. INTRODUCTION

The Kurushima Bridge is the link closest to Shikoku in the Onomichi-Imabari route of the Honshu-Shikoku Bridge Project. When completed it will be the first three stage suspension bridge in the world. Kumagai Gumi Co., Ltd. participated in the planning from the commencement of preliminary study in 1987, and, subsequently in the main construction, performed the submarine excavation for the anchorage foundation (4A) commonly used for both Kurushima Bridges 1 and 2. Because these bridges span the Seto Inland Sea National Park, many of the foundations are provided underwaters taking account of the landscape. Foundation 4A was also an underwater structure. Previous underwater foundations were constructed by leveling the sea bed with a large diameter excavator and setting a large scale caisson on a concrete pedestal. However, in this project a method was employed of setting a large scale caisson directly on the excavated surface. This method was first used in the construction of the main tower foundation for the Akashi Kaikyo Bridge project. Although the foundation for Akashi Kaikyo Bridge was built on comparatively uniform diluvium gravel deposits, this project was constructed on extremely complex bedrock, so that misgivings were voiced about the accuracy of merely excavating with a super large grab. Therefore, in this project in order to safely set a large scale caisson without the occurrence of slippage or slanting, the bottom of the excavated surface was leveled, and top priority was given to achieving a high degree of accuracy. In order to achieve this, computer aided construction was implemented in the entire submarine excavation process, beginning with a sea bottom topographical survey in the preliminary study prior to actual excavation, to the test excavation, the soft rock excavation and the hard rock crushing of the main excavation work, and the final finishing excavation. High quality control of construction was attained.

2. GENERAL DESCRIPTION OF THE PROJECTS

2.1 The Onomichi-Imabari Route

The Onomichi-Imabari route is located as the furthest West of the three bridges linking Honshu and Shikoku. It is a 60 km long automobile route linking the city of Onomichi in Hiroshima Prefecture on the Honshu end with the city of Imabari on the Shikoku end.

In route, it links nine islands of varying size including Mukaishima, Innoshima, Ikuchijima, Ohmishima, Ikatashima, Ohshima, and Umashima. (Figure 1)

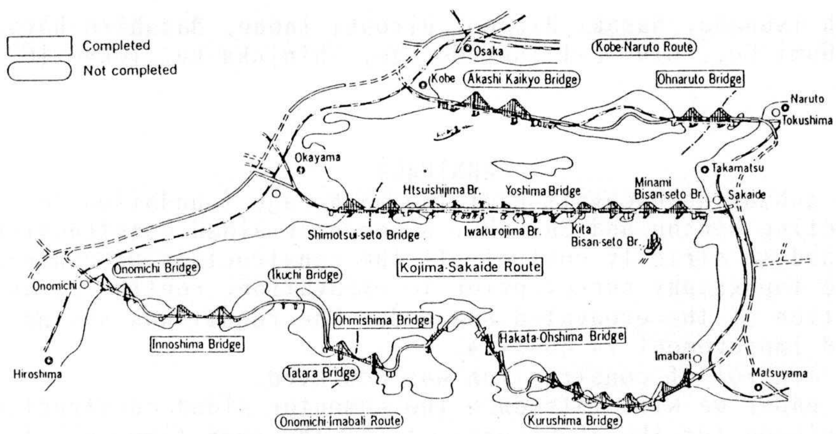


Figure 1 The Onomichi-Imabari Route of the Honshu-Shikoku Bridge Project

2.2 The Kurushima Bridge

The Kurushima Bridge spans approximately 4 km between Ohshima and Imabari on the Onomichi-Imabari route. It is a suspension bridge composed of the first, second, and third Kurushima Bridges (Figure 2). Of these, when the second Kurushima Bridge with a center span of 1030 m, and the third Kurushima Bridge with a center span of 1020 m are completed, they will be the eleventh and twelfth longest suspension bridges in the world.

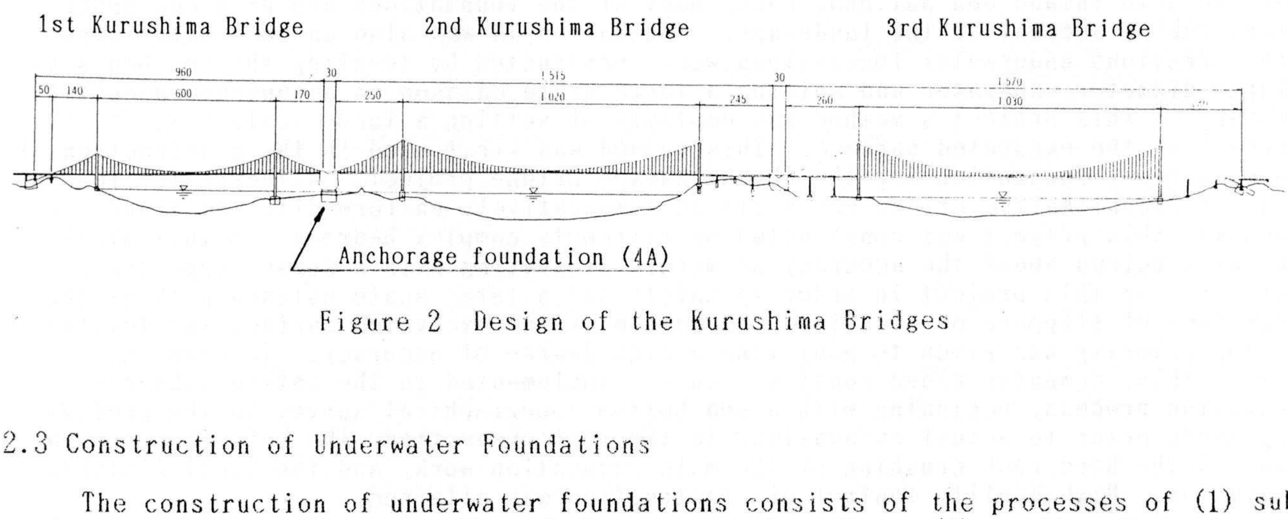


Figure 2 Design of the Kurushima Bridges

2.3 Construction of Underwater Foundations

The construction of underwater foundations consists of the processes of (1) submarine excavation and preparation of the excavated surface, (2) setting the caisson, and (3) casting the concrete, as shown in Figure 3. In this construction project, the method was employed of setting the caisson on the bottom surface after the submarine excavation and the leveling of the excavated surface were completed.

2.4 Submarine Excavation

The construction procedure for submarine excavation is shown in Table 1. In submarine excavation, first direct excavation is implemented by clearing away the sedimentary layer from the sea bed up to a depth of TP-24 as far as bedrock Class C_L using the large 5000 PS grab dredger Kanmon (Figure 4).

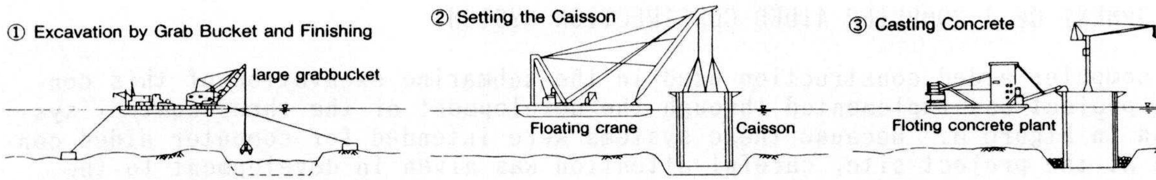


Figure 3 Construction of Underwater Foundations

Next, for bedrock layer Classes C_L − C_H where direct excavation is not feasible, the range TP-24 to P-29 is excavated using the 2200 PS grab dredger Sanyu equipped with a rock crushing stake (Figure 5). During this rock crushing process, first three rock layers of 1.0 to 1.5 m each are excavated roughly, and finally a finishing excavation of 1.0 m is made. The rock crushing stake used has a weight of 50 t. This stake was allowed to freely drop underwater to crush the rock, which was then excavated with a heavy bucket. Finally, for the range between TP-29 and TP-30 a switch was once again made back to the 5000 PS large grab dredger. The surface is carefully finished by ripper application using an ultra large bucket.

Table 1 Submarine Excavation Construction Procedure

Water depth	Grab dredger	Bucket employed	Submarine excavation construction procedure
Sea bed ~ TP-24.0 m	Kanmon 5000 PS	Ultra heavy bucket 17.5m³, 200 t	Direct excavation
TP-24.0 m ~ TP-28.0 m	San'yu II 2200 PS	Rock crushing stake 50 t Heavy bucket 8.5m³, 80 t	Rock crushing Crushed rock excavation Repeated 3 times 1.5m x 2 layers 1.0m x 1 layer
TP-28.0 m ~ TP-29.0 m	San'yu II 2200 PS	Rock crushing stake 50 t Heavy bucket	Finishing crushing Finishing excavation
TP-29.0 m ~ TP-30.0 m	Kanmon 5000 PS	Ultra heavy bucket Flat bucket 1.8m³, 52 t	Ripping Dredging excavation Confirmation sounding Repeated 4 times

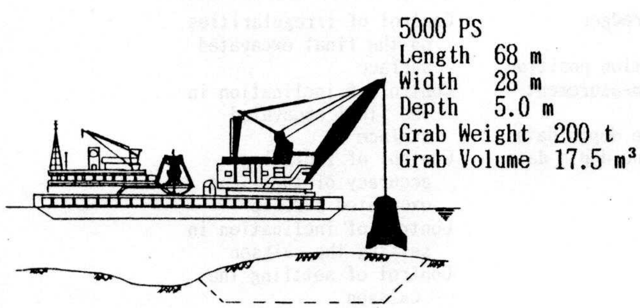


Figure 4

The Large 5000 PS Grab Dredger Kanmon

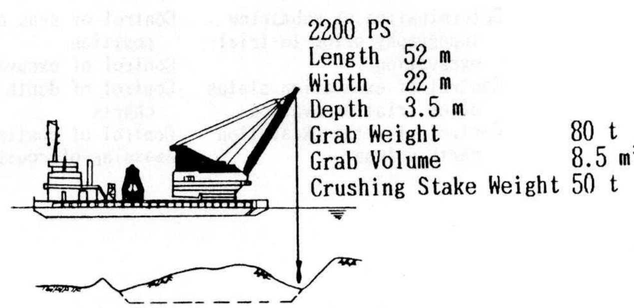


Figure 5

The 2200 PS Grab Dredger San'yu II Equipped With a Rock Crushing Stake

3. DEVELOPMENT OF A COMPUTER AIDED CONSTRUCTION SYSTEM

The computer aided construction used in the submarine excavation of this construction project was implemented through the development of the three control systems shown in Figure 6. Because these systems were intended for computer aided construction at the project site, careful attention was given in development to the following items.

(1) Simple enough for anybody to use, allowing personnel at the work site to perform all operations by themselves from measurement, analysis, output, to preparation of drawings. It can be used without sending a computer specialist or experienced technician to the work site office.
(2) Special hardware systems or expensive equipment was not used. Only computer equipment available anywhere was used. Since the measuring devices and computers were widely available, construction of the hardware system can be done at minimum cost, by incorporating equipment currently being used and rental equipment.
(3) Since computers are often moved from place to place, to be used for on-site measurement control, and then back to the office for analysis, easily portable laptop or notebook computers are used.
(4) For data which is crucial to determine immediately, measurement and analysis can be immediately processed on board the work ship so that real time display is possible. The data displayed here must be immediately used for the next step.
(5) There are savings in time, personnel, and expense in the work required for measurement, analysis, output, and preparation of drawings. By employing this system, none of the categories of time, personnel, nor expense need be great. Analysis, output, arrangement of data, and preparation of drawings can be all accomplished through unmanned operation.

3.1 Submarine Excavation Status Control System

The submarine excavation status control system records the status of the sea bed prior to excavation in the survey work stage, and the status after trail excavation. It displays on screens, automatically analyzes and produces drawings for data diagrams of measurement points, water depth diagrams, contour maps, earth volume variance diagrams, excavation cross sectional diagrams (vertical or horizontal), and bird's eye views. The flow of the submarine excavation status control system is shown in Figure 7.

Submarine Excavation Project Computer Aided Construction System

Submarine Excavation Status Control System	Routine Submarine Excavation Control System	Sea Bed Finishing Excavation Control System
Determination of submarine topography prior to trial excavation	Control of grab dredger position	Control of irregularities on the final excavated surface
Control of excavation status after trial excavation	Control of excavation position	Control of inclination in the final excavated surface
Control of trial excavation earth volume	Control of depth measurement charts	Control of finishing accuracy of the final excavated surface
	Control of routine depth data	Control of inclination in setting the caisson
	Amassing of routine depth data	Control of settling the caisson
		Simulation of caisson setting

Figure 6 Computer Aided Construction System

3.2 Routine Submarine Excavation Control System

The routine submarine excavation control system controls the locations where the grab dredger is moored within the work area, and where excavation is being done every day in submarine excavation projects. Then it measures and stores as routine data the excavated earth volume, the excavated depth, and the excavated shape at that location each time the grab dredger shifts position. Further, based on the data amassed, it controls the overall excavated earth volume, and the finished shape of the excavated topography and excavation cost. The flow of the routine submarine excavation status control system is shown in Figure 8.

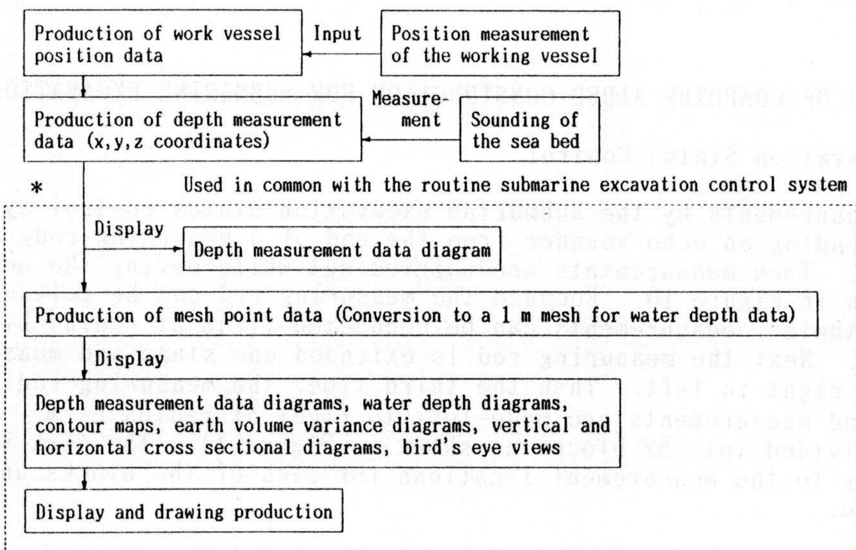


Figure 7 Submarine Excavation Status Control System Flow

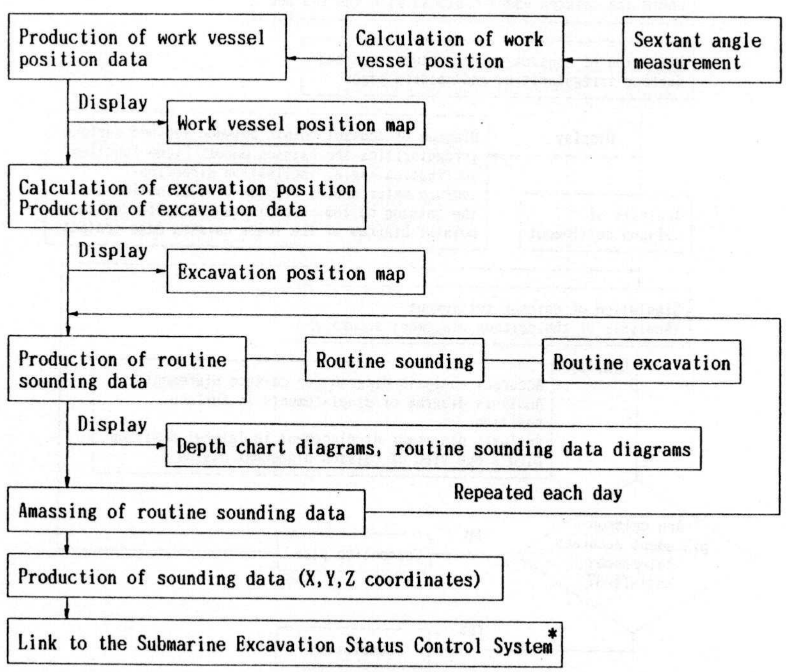


Figure 8 Routine Submarine Excavation Control System Flow

3.3 Sea Bed Finishing Excavation Control System

The sea bed finishing excavation control system is used when the excavation approaches the final level for finishing excavation. It also controls irregularities, inclination, and finishing accuracy of the final excavated surface, as well as control of inclination and settlement of the caisson, and simulates caisson placement. It is extremely important to know the status of the excavated surface on the sea bed and its accuracy at the contact area of the edges of the caisson. This system simulates on how much the caisson will slant when placed on the final excavated surface, and how much of an error will result. If it is anticipated that the accuracy in laying down the caisson will vary beyond the tolerance, an effective corrective plan can be immediately formulated. The sea bed finishing excavation control system flow is shown in Figure 9.

4. ACTUAL EXAMPLE OF COMPUTER AIDED CONSTRUCTION FOR SUBMARINE EXCAVATION

4.1 Submarine Excavation Status Control

The depth measurements by the submarine excavation status control system are performed by suspending an echo sounder from the end of a measuring rod, and lowering it into the water. Then measurements are carried out while moving the echo sounder in an arc as shown in Figure 10. Because the measuring rod can be telescoped in three stages lengthwise, measurements can be conducted first at radius L_1 m by rotating left to right. Next the measuring rod is extended one stage and measurements are made at radius L_2 right to left. Then the third time, the measuring rod is extended a second stage, and measurements are made left to right at radius L_3 m. The investigation area was divided into 52 blocks as shown in Figure 11. The work vessel was moved successively to the measurement locations for each of the blocks and the measurements were made.

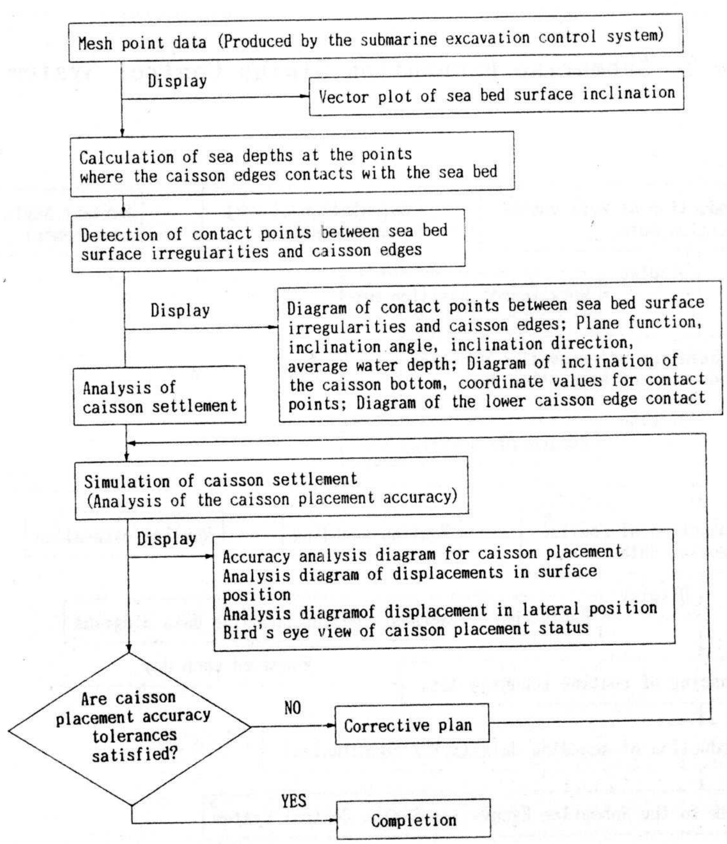
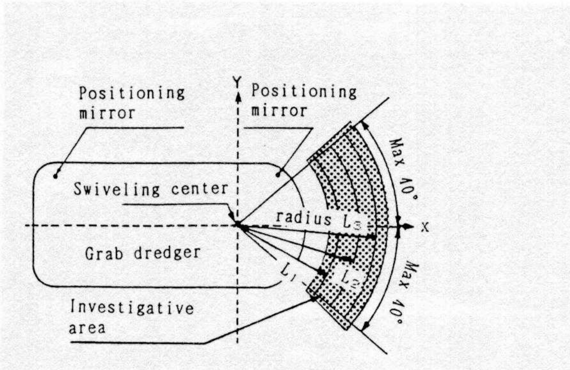


Figure 9 Sea Bed Finishing Excavation Control System Flow



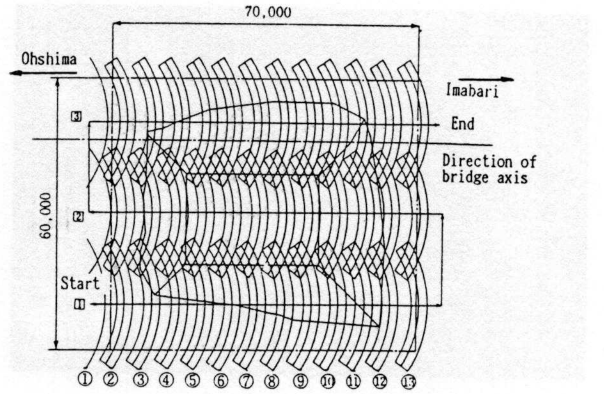


Figure 10 Plan of Grab Dredger

Figure 11 Division of the Sounding Investigation Areas into Blocks

Examples of the submarine excavation status control are shown in Photos 1 to 6. The depth data measurements are converted in real time to numerical values and the depth contours are displayed in color as in Photo 1. The sounding diagram is derived from the sounding data measurements by imposing 4331 mesh points (61x71=4331) on the 4200 sq m (60x70=4200 sq m) measurement area to obtain water depth data at the 1 m mesh intervals. Photo 2 shows a display of a sample sounding diagram. The computer screen is not large enough to display all mesh points at one time. Here only 1/25 of the total measurement area is displayed. The area of this example corresponds to X coordinates between 42 m and 56 m, and Y coordinates between 36 m and 48 m. Photo 3 shows the submarine topography before excavation, and Photo 4 shows the submarine topography after trial excavation. A submarine contour map is shown in Photo 5, and an Excavation Profile Diagram in Photo 6.

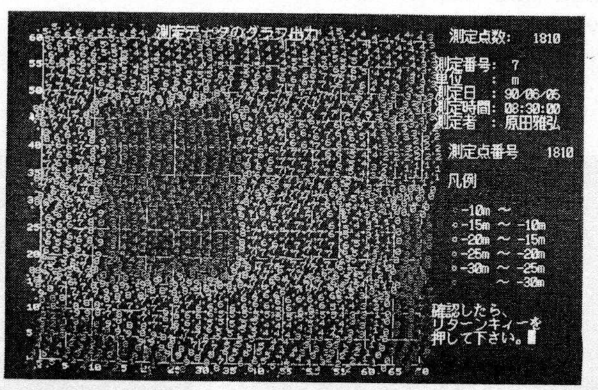


Photo 1 Depth Data

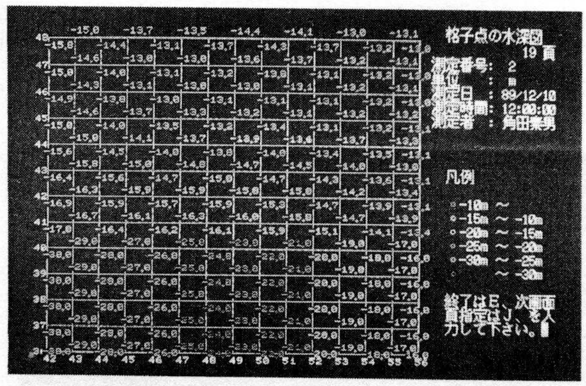


Photo 2 Sounding Diagram

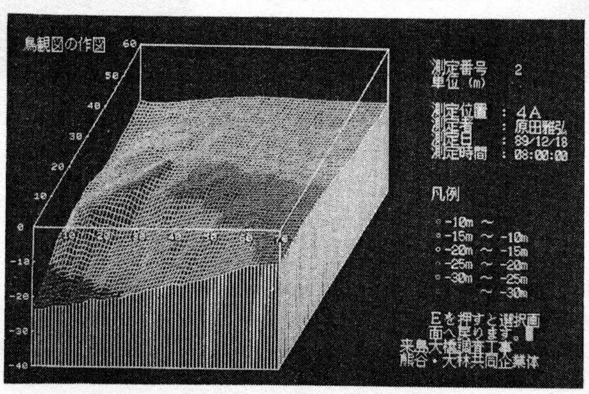


Photo 3 Submarine Topography Before Excavation

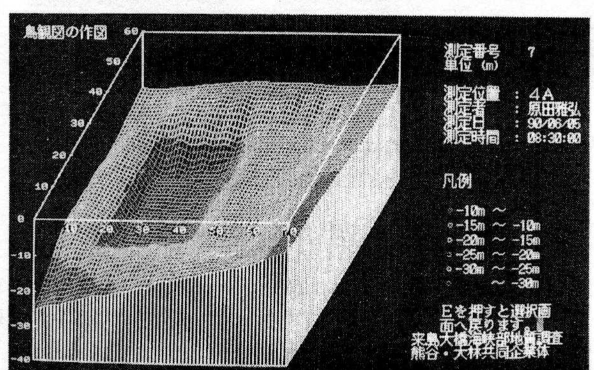


Photo 4 Submarine Topography After Trial Excavation

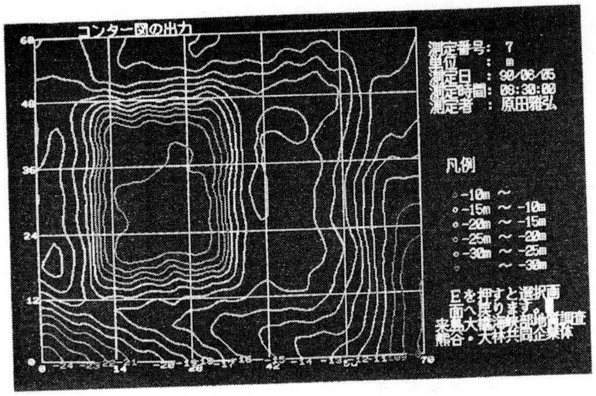


Photo 5 Submarine Contour Map

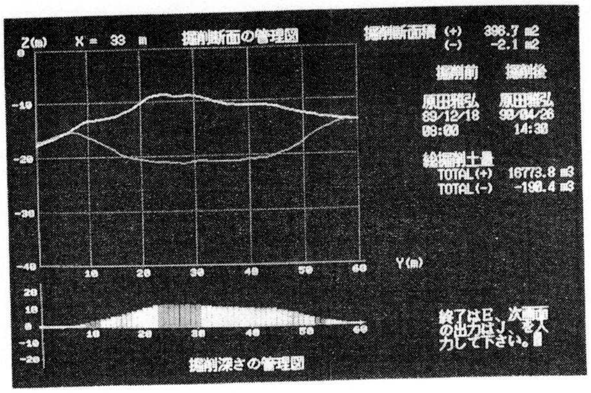


Photo 6 Excavation Profile Diagram

4.2 Routine Submarine Excavation Control

Control of routine submarine excavation is performed through an analysis of the grab dredger position and the excavation position as shown in Figures 7 and 8. Generally, the position and direction of the vessel are obtained by plotting sextant measurements in circular coordinates. Here the position of the grab dredger is calculated automatically by entering the sextant measurements in the computer. Once the position and direction of the grab dredger are obtained, the excavation area can be derived from the length of the grab arm and the angle of rotation. When the excavation for the day was completed in a project, depth data measurement was collected every time for each excavation by the same method as Figure 10. The accumulated routine submarine excavation data is summarized and depth data measurement is produced. The status of the submarine excavation can thus be controlled.

Figure 12 shows an example of a routine submarine excavation control system.

Photo 7
Position Analysis for the Grab Dredger

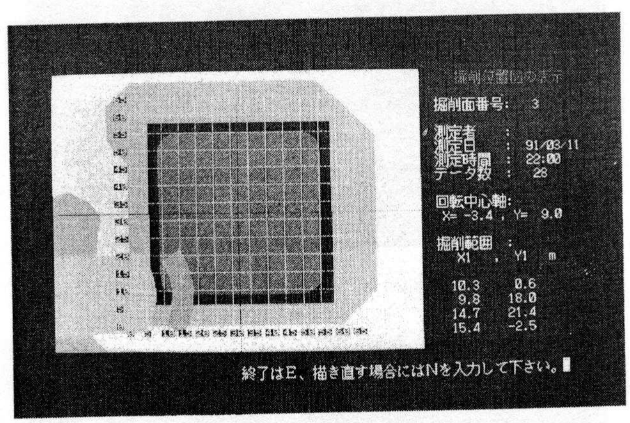


Photo 8 Excavation Position Analysis

4.3 Sea Bed Finishing Excavation Control

The sea bed finishing excavation control step calculates the water depth data for the caisson edge from the submarine topography data obtained during the submarine excavation status control and the routine submarine excavation control stages. Then from the lower edge points of the caisson, the three points which will support the caisson are singled out by detecting the contact between the caisson edge and protrusions on the sea bed. The inclination angle and inclination direction of the caisson

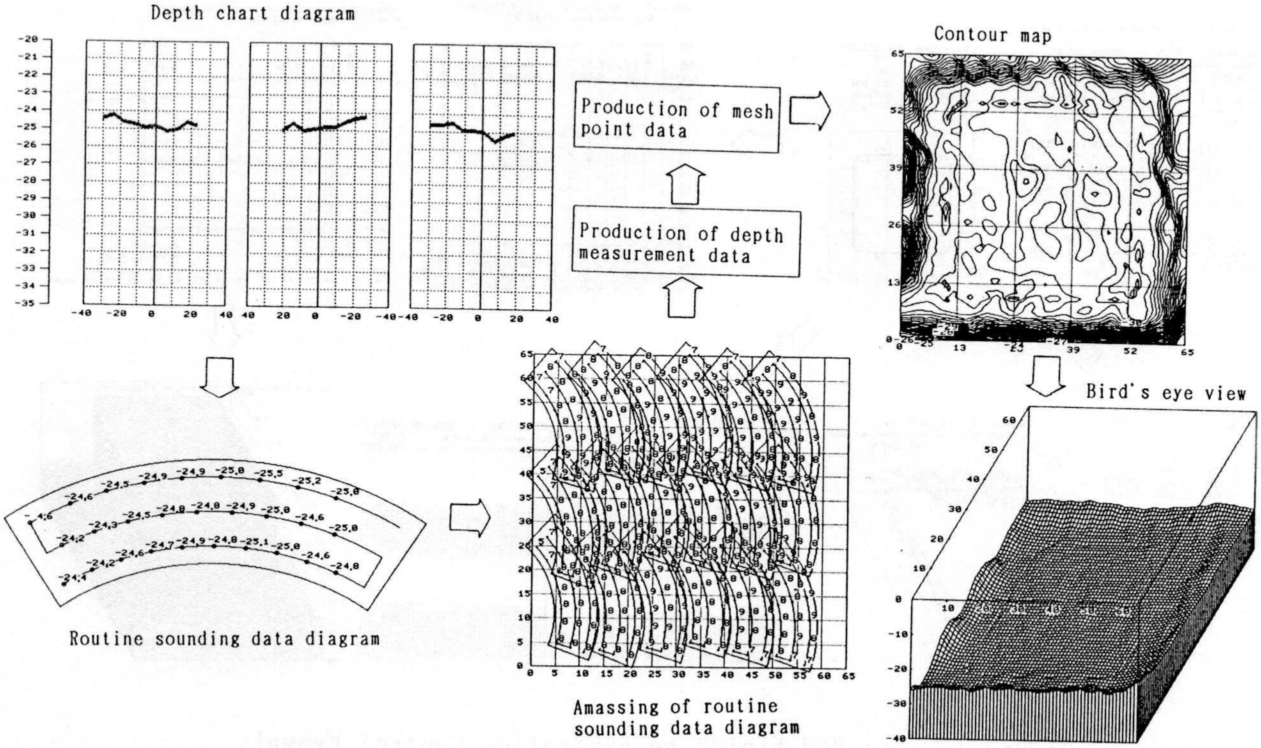


Figure 12 Routine Submarine Excavation Control Example

edge are analyzed when these three points support the caisson. At the same time, a prediction is made of the placement status of the caisson on the sea bed by simulating the inclination and inclination angle of the overall caisson, the eccentricity magnitude or displacement of the caisson in relation to the placement position. When the eccentricity of the caisson greatly exceed tolerances, because we were able instantly to produce a solution as to which sea bed protrusion making contact with the caisson edge should be scraped off, we were able to plan effective countermeasures. A highly accurate finishing excavation could be performed. Figure 13 shows an example of sea bed finishing excavation control.

5. CONCLUSION

Compared with construction projects on land, marine construction is greatly affected by meteorological and oceanographic natural conditions. An automatic system for marine construction projects must be a construction system that allows for changes in the natural environment on an hour by hour basis. Furthermore, bulldozers and power shovels are standard construction equipment for land construction. However, since standards and performance of work vessels for marine construction projects vary, a different system must be developed for each type of work vessel, in order to automate marine construction. This kind of problem is a difficulty in automating marine construction projects. However, as we explained in this report, a personal computer has enough function to see the topography of the sea bed or the status of the excavation. Further, when placing a caisson, it has the ability to make calculations predicting how the caisson will set down, as well as judgment to determine where on the submarine base surface should be scraped off for more accurate placement. Since the system this time employed a sextant for determining the positions of the work vessel and the excavation site, manpower was required for the position determination. But if light reflecting targets and homing type angle measuring devices are used, it is expected that position determination can be easily automated. Moreover, since the

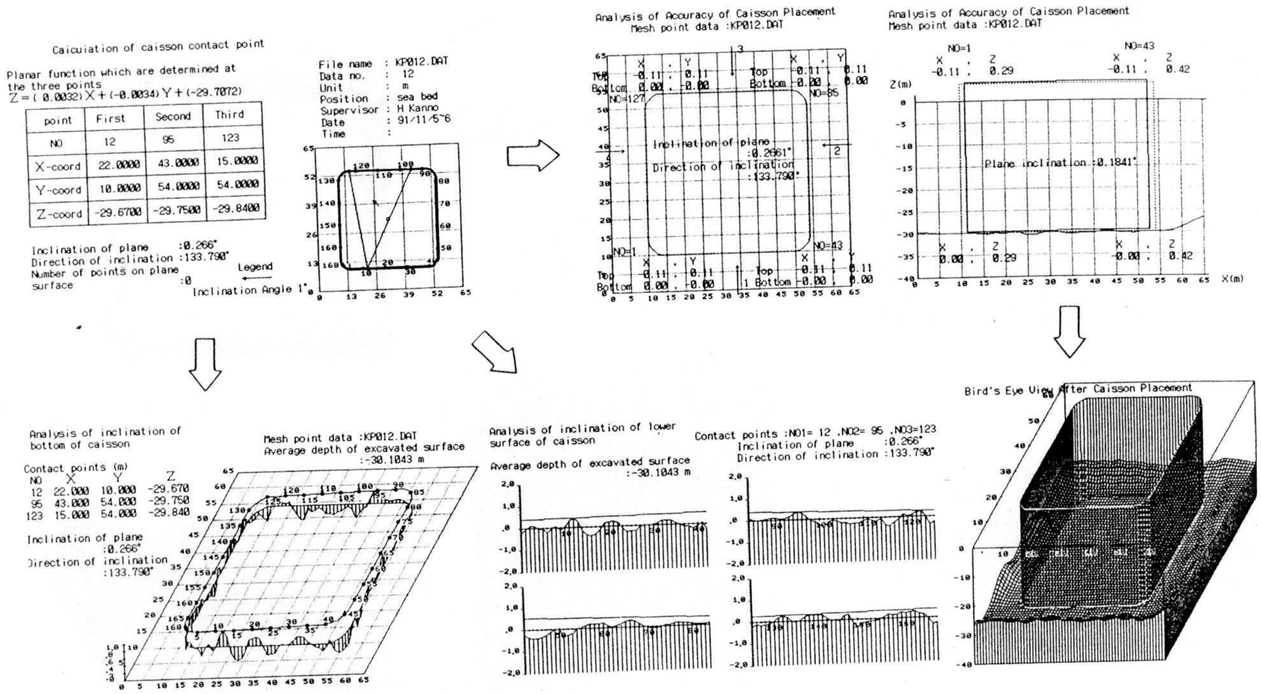


Figure 13 Sea Bed Finishing Excavation Control Example

work vessels are firmly anchored and moored by six sinkers and six ropes, if the mooring rope can be wound by a winch, movement of the work vessel can also be automated. If each of these automatic movement control technologies were to be completed, automated construction in marine projects would no longer be an impossible dream. We believe realization to be possible. We have tremendous expectations for future marine construction projects and robot technology research.

On the other hand, the research and development of automated construction systems, and robot technology is all well and good, but there has to be a major emphasis on introduction of new technology somewhere at civil engineering sites. In smoothly introducing computer aided construction systems at project sites, it is important that the system be superior, but even more than that, it is essential that the specific know-how of already experienced site supervisors be respected and incorporated into computer aided construction. Even for efficient new construction methods, if previous methods are ignored, it is extremely difficult for an entirely different approach to be adopted and established in the work site. Computer aided construction technology must be positioned as an extension of technology previously cultivated at construction sites. It is most important that it meet the severe demands of the site supervisor, because the site technician is the one who must put computer aided construction into practice.

We hope that we have made some contribution to the development of future computer aided construction technology. We would like to express our deep appreciation for all those who helped in the compiling of this paper.

6. REFERENCE

1) "Honshu-Shikoku Bridge Project", Japan Society of Civil Engineers, October 1988
2) "Kurushima Bridge", Catalog, Honshu Shikoku Bridge Authority, Third Construction Bureau, Imabari Construction Office, March 1991
3) M. Tsunoda, M. Hirano, K. Okazaki, M. Harada; "Development and Application of a Hydrographic Surveying System for the Control of Submarine Excavating Conditions", 1991, Seminar on Engineering for Coastal Development, PP.159-168, September 24-25 1991 Singapore, The Kozai Club