AUTOMATION AND ROBOTICS OF UNDERWATER CONCRETING IN HUGE SCALE STEEL CAISSON, THE MAIN TOWER FOUNDATIONS OF THE AKASHI KAIKYO BRIDGE

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SUMMARY

Antiwashout underwater concrete totalling about 500,000 m^3 in volume was placed for the two underwater foundations of the Akashi Kaikyo Bridge, to be the world's longest suspension bridge when completed. Placing took a year under severe marine conditions with a maximum 8-knot tidal current and a maximum depth of 60 m. Because the concrete had to be placed in layers over the wide area of a steel caisson, which acts as the formwork, and under great depth, a cleaning robot to clean the undersea bedrock surface was used, production and placing of concrete was automated, and a construction joint treatment robot was used to obtain good quality concrete.

1. INTRODUCTION

The Akashi Kaikyo Bridge, currently under construction, will be the world's longest suspension bridge with a total length of 3,910 m (1,990 m center span) when completed in 1997. The two main tower foundations, shown in Fig. 1, are constructed in water where the maximum tidal current is 8 kt and the maximum depth 60 m. The construction method is as follows: First, excavation of underwater bedrock, second, installation of steel caisson, then concreting within the caisson to form the foundation. This is known as the laying-down caisson method. In the case of No. 2 pier (2P), for example, the steel caisson is double-walled and cylindrical, its outer diameter is 80 m, inner diameter, 56 m, and height, 65 m, as shown in Fig. 2.

In the inner core (diameter: 56 m) of the caisson, the underwater concrete was placed in 14 layers from 60 m to 10 m below sea level. The volume of concrete placed at one time was between 9,000 m^3 and 10,000 m^3, continuously placed over three days and nights. After the concrete had hardened, the construction joints were treated using an unmanned underwater joint treating machine. The portion between the double walls was divided into 16 sections. About 9,000 m^3 was placed at one time from 60 m to 5 m below sea level.

The total volume of underwater concrete was 270,000 m^3 for 2P and 240,000 m^3 for 3P (No. 3 pier). The underwater concreting was completed in a year. The operation of machines and divers at such a great depth and in fast tidal current is limited, so there are generally problems with construction period and quality. In this construction work, therefore, these problems were solved by automating and robotizing the operations as follows.

1) An automated cleaning machine was developed for the removal of remaining sand and rock at great depth (-60 m), and over about 4,000 m^2 in area after grab excavation. This machine cleaned the bedrock surface.

2) In a fully automated operation, about 10,000 m^3 of underwater concrete was placed per pour, using 24 pouring pipes over the wide area of 2,600 m^2 to a thickness of 4 m.

3) In cleaning about 2,600 m^2 of construction joints under deep water, a robot developed specifically for the purpose was used.

Details are given below.

2. AUTOMATION AND ROBOTICS IN CONSTRUCTION MACHINERY

2-1 Development of Bedrock Cleaning Robot

After completion of grab excavation, the seabed is covered with remaining sand and rock to a thickness of 0-50 cm and these cannot be removed by grab bucket. To ensure good adhesion between bedrock and concrete, it was necessary to remove the sand and rock and clean the bedrock surface.

The great depth of 60 m, the wide area of about 4,000 m^2 that needed treating, and uneveness of about ±0.5 m on the bedrock surface, made the operation of conventional machinery considerably difficult. To do the job, a bedrock cleaning robot operated by remote control was developed.

This robot, which is able to rotate, bend, extend and contract the air lift pipe (ø300), cleans a circle 16 m in diameter. The robot is operated remotely while monitoring the suction conditions using the underwater TV camera installed on the tip of the air-lift pipe and observing the cleaning locus using a CRT screen in the operator's room on the caisson.

As cleaning was completed in one area (16 m in diameter), the robot was moved, 16 moves were necessary for the cutting edge area and 14 for the inner core area, as shown in Fig. 4. Two robots were used. According to performance record for 3P, the actual work took 20 days, a total of 430 actual working hours, of which 160 hours were for preparatory work. Performance record of 2P was similar to 3P.

2-2 Development of Concrete Production and Placing Machine

1) Concrete placing procedure

The underwater concrete was produced on a batcher plant barge and moved to the pumping station on the caisson using barge-mounted concrete pumps. At the pumping station, a 40 m^3 agitator received the concrete and distributed it to six concrete pumps (with two units in reserve). From each concrete pump, the concrete passed through a 200 mm-diameter pipe to the distribution valve, where the concrete was delivered into four pipes. The 24 pipes were supported by lifting apparatus which lifted the pouring pipes as the level of concrete in the caisson rose. To check the concrete coverage, a TV camera was installed on the tip of each pouring pipe. (Fig. 3)

2) Large-scale concrete plant barge

The site is in an area of fast tidal current up to 8 kt, and so a conventional concrete barge would be difficult to moor and the amplitude of rolling and pitching of the barge induced by vortices around the caisson makes it difficult to weigh the concrete materials. Therefore, special concrete barges were built for 2P and 3P, each equipped with material storage silos, concrete plants, and concrete pumps able to store material, produce and pump the concrete in quantity. The barge was equipped with a mooring system which can hold it even under fast tidal currents up to 8 kt and a roll and pitch correction system to ensure an accuracy of over 1/200 in the weighing of materials.

To prevent concrete placing from being interrupted by sudden changes in meteorological and marine conditions, or similar, a nonreplenishment policy was adopted, so all concrete materials were loaded on the barge in advance. Based on this decision, since the loading capacity of the largest barges in Japan is 24,000 t, the volume of concrete placed at one time was determined to be 9,000-10,000 m^3. (Photo 1) Since the properties of underwater concrete can be greatly affected by even slight changes in the surface water ratio of sand, a sand stabilizer (Fig. 5), which dehydrates the sand with a centrifugal force of 180 G, was used to stabilize the quality of fresh concrete.

3) Concrete distribution system

Where concrete is to be placed over a wide area, such as this case of 2,600 m^2, the area is usually divided into several sections by bulkheads, and concrete is placed separately in each section. Although this method is effective in keeping the designed distance of concrete flows, in the case of these main tower foundations, the weight of steel bulkheads would be over 6,000 t, so a distribution system through which the designed flow distance can be obtained without bulkheads was developed.

The distribution system is outlined as follows: The pouring pipe takes charge of each pipe's placing area, which is the area formed by lines perpendicular to and equidistant between the pipe and all surrounding pipes, as shown in Fig. 6. To guarantee the quality of the concrete, the 24 pouring pipes were set to keep the flow distance of concrete to less than 8 m. The placing speed was adjusted so that the volume placed by each pouring pipe is proportional to the area in charge.

Concrete was pumped from the concrete plant barge into the 40 m^3 agitator, as already described. To distribute concrete from the agitator to the 24 pouring pipes, 6 concrete pumps are used, and 6 distribution valves direct it to the pouring pipes, as shown in Fig. 7. The distribution valves distribute concrete from one concrete pump to 4 pouring pipes. The control of the pumped volume depends on adjustments to the number of pump strokes, so the system was made automatic with a feedback mechanism. During concrete placing, the distribution valve setting and the pump stroke rate were fed into a computer and printed out every hour. Any large fluctuation between placing volume and designed volume led to a recalculation of the distribution and the pumping speed, and changes in the switching of the distribution valves.

4) Pouring pipe lifting apparatus

The concrete pouring pipes exceed 65 m from the top of caisson to the seabed. They must be positioned before placing and raised according to the surface level of concrete during placing. Although operations such as these are normally done by crane, as there are so many pouring pipes it is difficult to position the cranes. As a result, a special lifting apparatus was developed. Before concreting, this apparatus sets the pouring pipes by joining each pipe.

The length of pouring pipes is 3-4 m. During placing, each time the concrete level rises by 3-4 m, the upper pouring pipe is disjointed and lower pouring pipe jointed.

If the tip of a pouring pipe is set too deeply into the placed concrete, concrete placed a few hours earlier would be disturbed. On the other hand, if the pipe is raised above the concrete surface, segregation due to free fall would occur. To prevent these adverse effects, a TV camera for monitoring was installed on the tip of each pouring pipe and concrete placing was carried out while checking the coverage (5-10 cm).

2-3 Development of Underwater Construction Joint Treating Machine

Because the inner portion was placed in layers of about 4 m high in lift, particulates separated from the concrete and marine snow accumulated to about 5 mm in thickness on the surface of the concrete after placement. This had to be removed in order to obtain sound concrete at construction joints. Because of the great water depth, and the wide area to be treated, a special underwater construction joint treatment robot, with remote control capability from the caisson, was developed as shown in Fig. 8. The rotary brush on the front of the robot disturbs and disperses the particulates in water and they are pumped away from the caisson using a submerged pump. By traveling along a spiral path outwards from the center of the caisson, increasing in radius by 1-1.5 m per rotation, it cleans the entire area.

According to performance record for 3P, the actual work took 31 days, a total of 313 actual working hours, of which 37 hours were taken up by preparatory work for a total cleaned area of 23,000 m^2. Performance record of 2P was similar to 3P.

3. CONCLUSIONS

The placing of a large volume antiwashout underwater concrete under extremely severe conditions was completed in a short period of time. As a result, an extremely flat concrete was placed as shown in Photo 2. The results of core boring showed the expected strength for both the general portion and the construction joints, and the adequacy of the construction method for the work was verified.

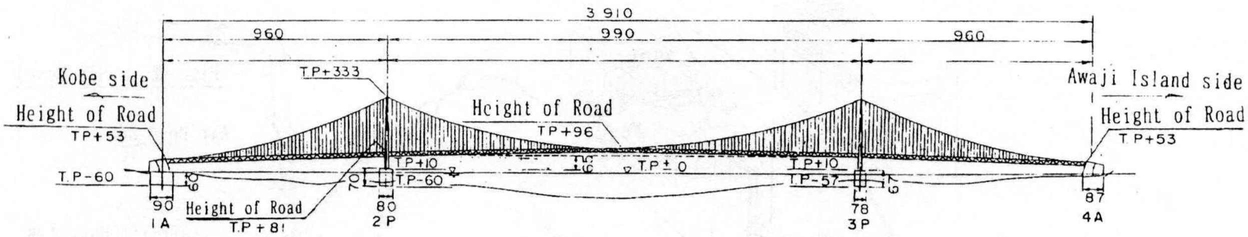
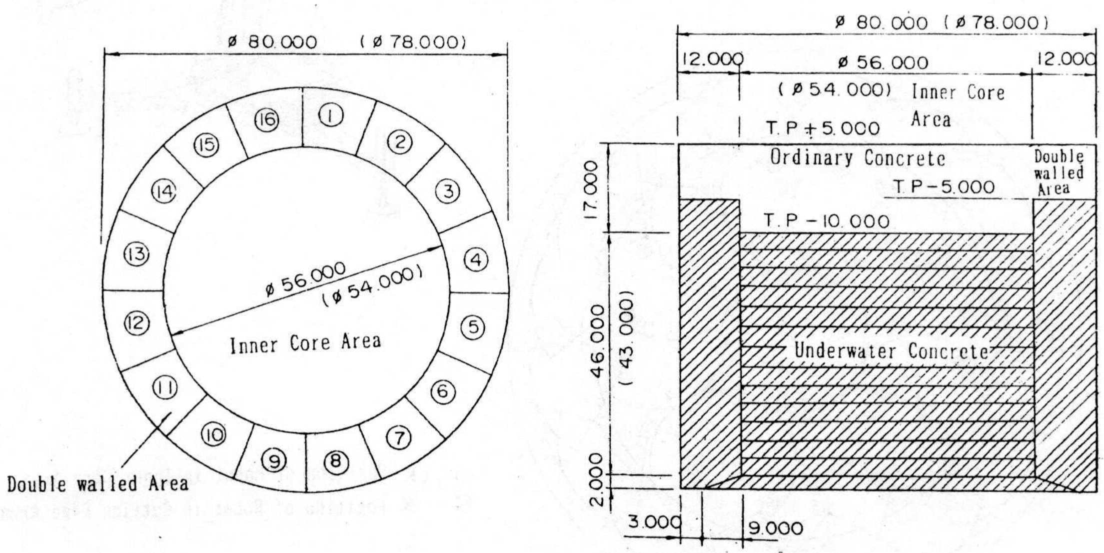


Fig.1 General Drawing of Akashi kaikyo Bridge



Note : Dimensions for pier 3P are given in parenthesis

Fig.2 Placing of Underewater Concrete

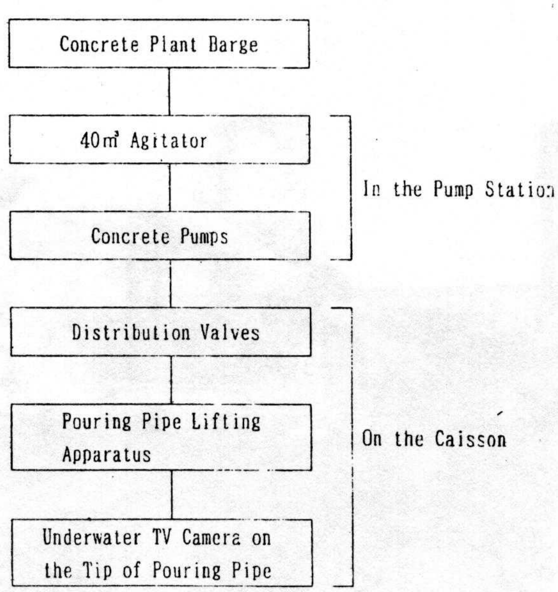


Fig.3 Concrete Placing Procedure

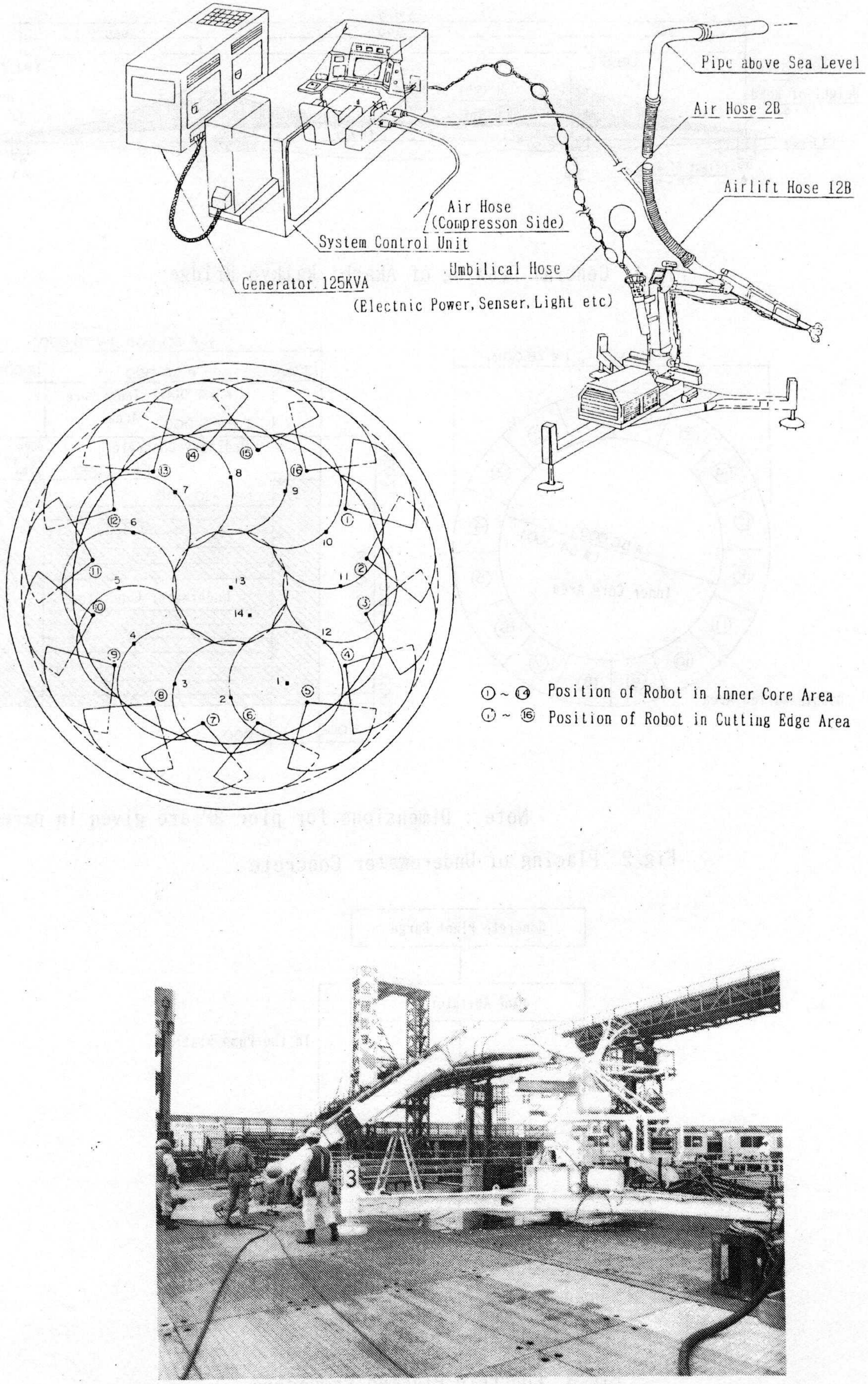
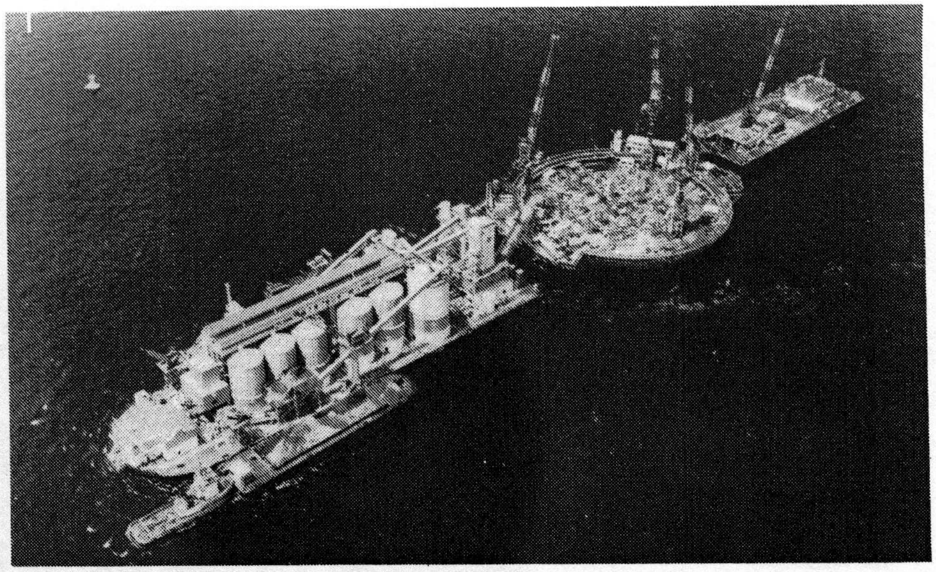


Fig. 4 Bedrock Cleaning Robot and Movement Pattern of Robot



Specifications of plant Barge

Barge	Load capacity of 24,000 t class
Hull structure	150m in length, 40.0m in width, depth 8.5m and 6.5m in draft
Mooring windlass	100t × 5m/min × 8 units
Batcher plant	2.5m³, horizonal biaxial forced mixer × 2 series
Cement silos	1,600t × 2 units
Aggregate silos	Coarse aggregate 1,085m³ × 2 units, 1,189m³ × 4 units, fine aggregate 1,316m³ × 4 units
Chilled water system	300,000Kcal/H × 2 units, 750,000Kcal/H × 1 units, 255,000Kcal/H × 4 units
Sand stabilizer	SS-24 (50m³/H) × 2 units
Concrete pump	IPF 110S (110m³/H) × 3 units × 2 serise

Phote 1 Concrete Plant Barge, Steel Caisson, Material Storage Barge

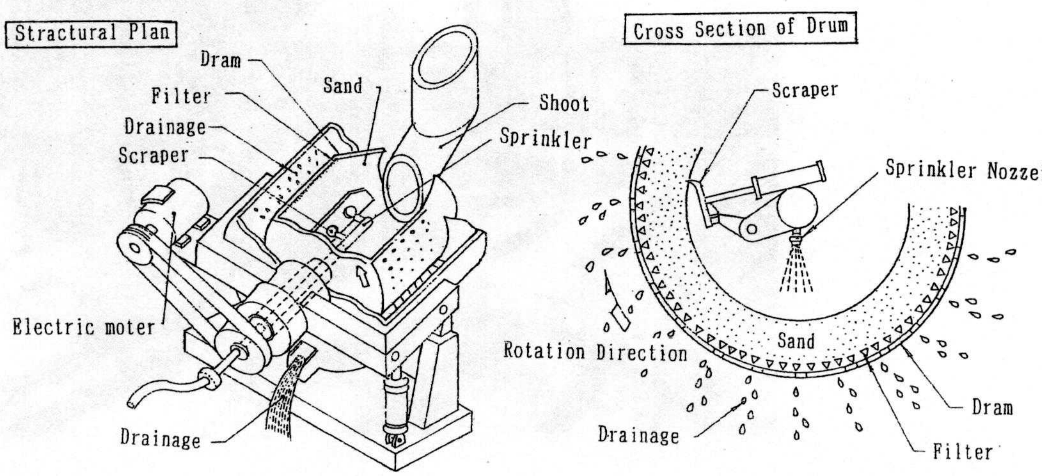


Fig.5 Sand Stabilizer (2.4m³/Batch)

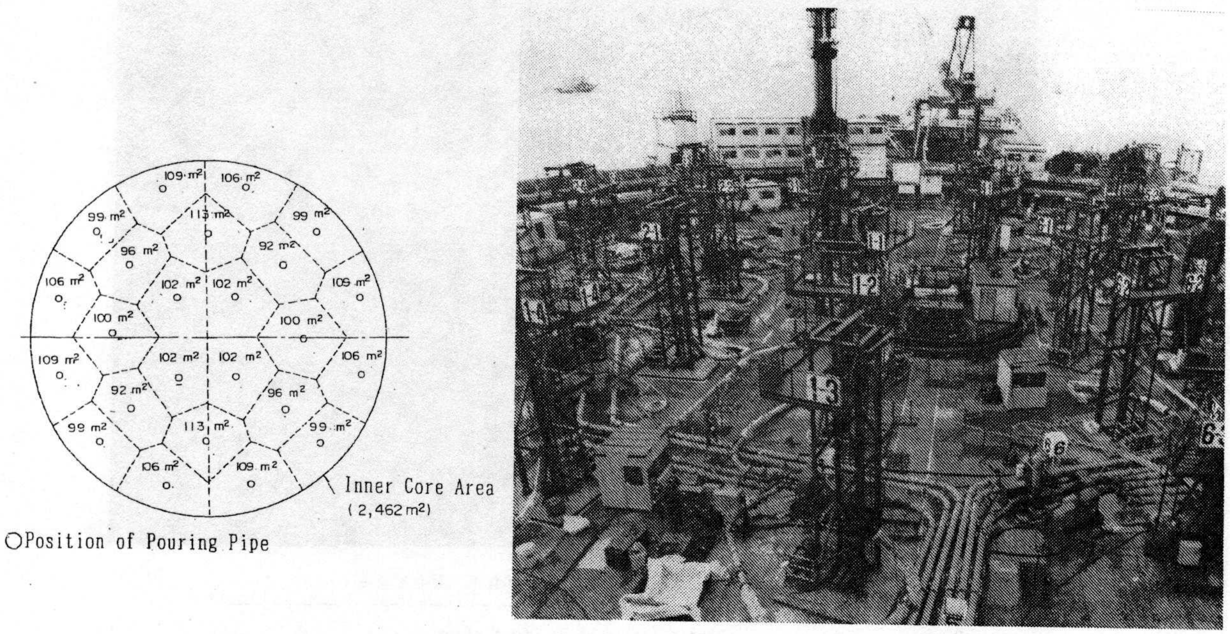


Fig. 6 Layout of Pouring Pipe and Concreting Apparatus on the Caisson

(φ200 Concrete Pipe, Distribution Valve and Pouring Pipe Lifting Apparatus)

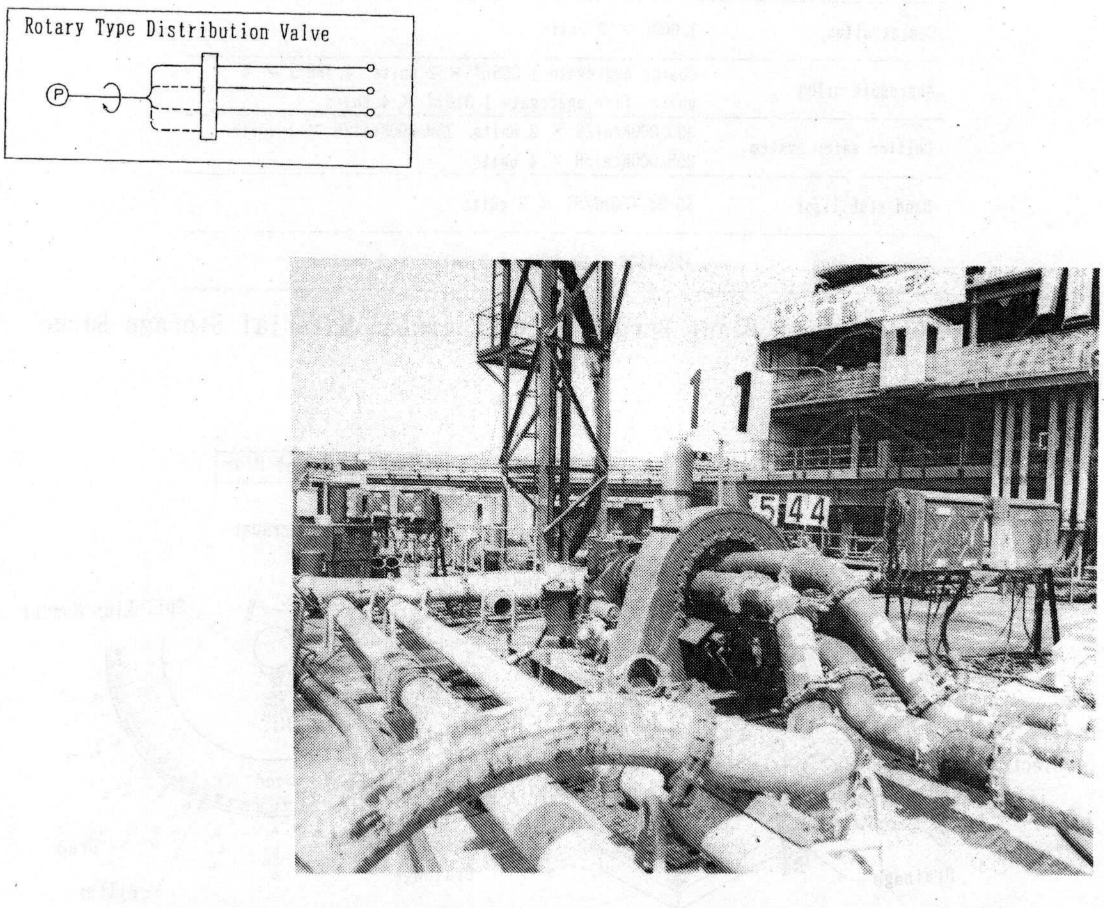


Fig. 7 Concrete Distribution method and Rotary Type Distribution Valve

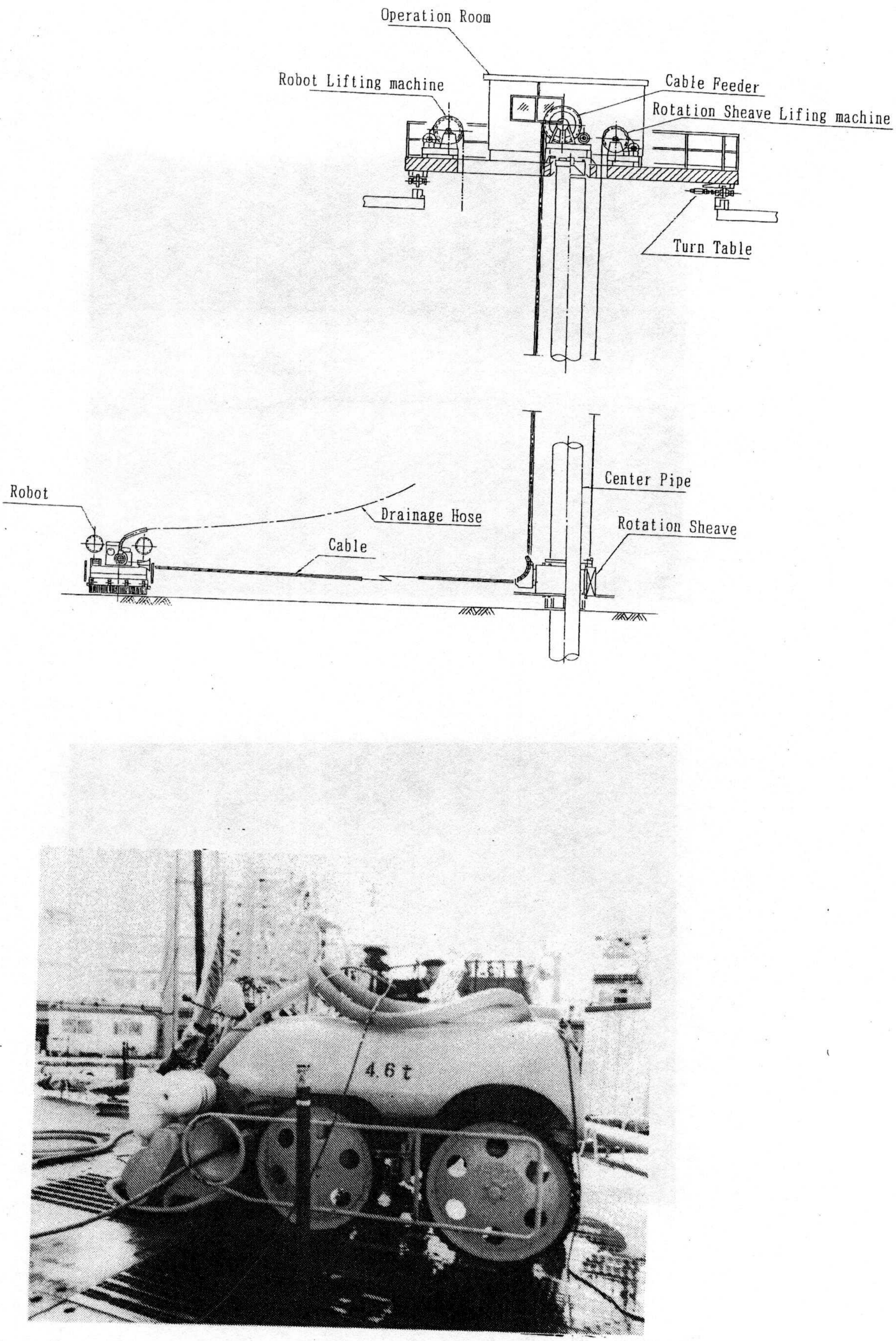
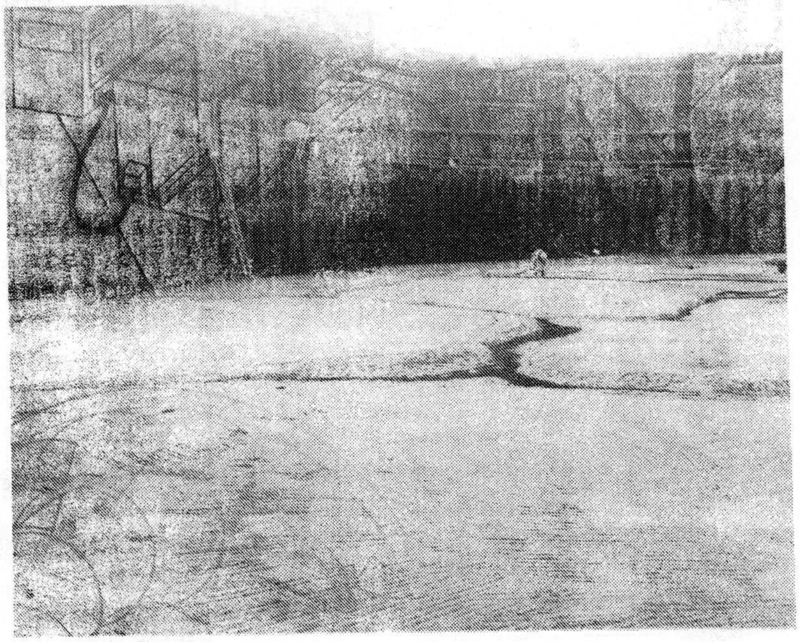
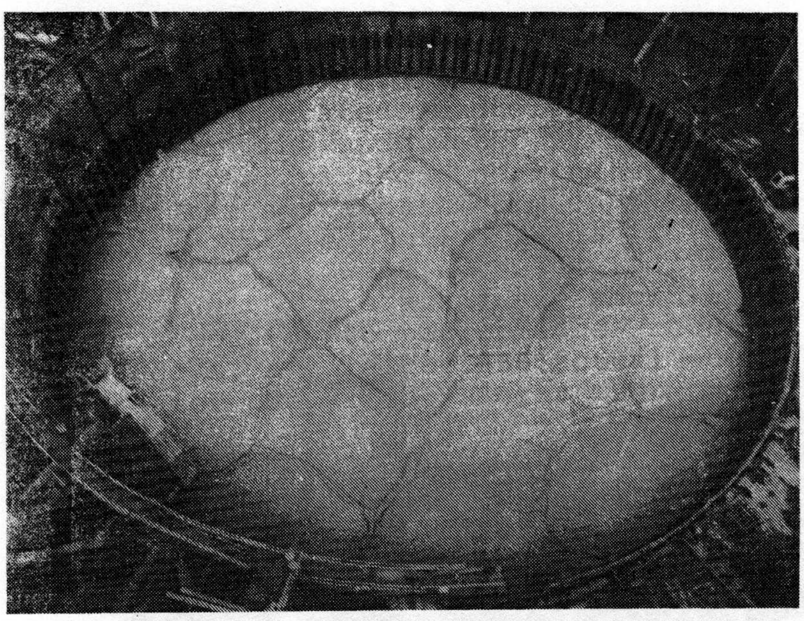


Fig.8 Underwater Construction Joint Treatment Robot





Phote 2 The Surface of Underwater Concrete after Dryed Up