Development and the Result of Practical Works of Concrete Floor Finishing Robot

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ABSTRACT

We developed a concrete floor finishing robot (the SURF ROBO) in order to eliminate heavy-duty work and increase the efficiency of concrete floor finishing work. For about one year after development, several SURF ROBOs have been used at the practical construction sites and satisfactory results were obtained in respect of quality and efficiency.

Two (2) sets of four (4) piece trowels are provided, the trowels rotate reversely against each other around the caterpillars and the trowels make the concrete floor smooth as well fine as by the skilled worker.

After practicing with this robot, we found that it has the capacity for finishing of a concrete-floor surface of 300 m2 per hour and it provided the same effect of a concrete-floor direct finish with precision as a plasterer. But, as working time can not be reduced by the SURF ROBO because of bleeding water, we have been developing the dehydration robot.

1. INTRODUCTION

Recently,in construction industry, " Labor shortages " and " aging workers " have reached the level where they may significantly effect the actual progress of construction works.

One aspect of construction works which is especially effected by these trends, is the concrete floor finishing work. Since this work entails the use of heavy labor and long work hours, the prospects of recruiting young workers are not encouraging. Therefore, needs for robotization in this work have been particularly seen in comparison with other works.

In order to meet such needs we started developing a robot for this work in 1983, completed an experimental unit in November 1985, and finished the machine for practical use in December 1986. Thereafter, as a result of actual construction work usage, improvements were made on the original model, and at present, more than 20 sets of the robot are being used at construction sites.

This paper describes about a concrete floor finishing robot (the SURF ROBO) and the result of practical work.

2. THE NECESSITY OF ROBOTIZATION

In Fig.1, the concrete floor finishing procedure is outlined. Normally, the placing of concrete is started at around 8 o'clock in the morning and doesn't end until the evening. The finishing work begins in accordance with the hardening of the placed concrete. As the time needed for hardening of concrete is affected by the temperature and humidity, in the cold temperatures, the end of the finishing work usually delays until daybreak the next morning. Sometimes the workers are on location for more than 20 hours. The inefficiency is clear from the fact that the major portion of the time is spent waiting for the concrete to harden. Besides, there are the following problems :

(1)In case of manual trowel finishing, the workers have to engage in very hard labor maintaining a painful position.

(2)Using conventional engine-driven trowels late at night or early in the morning may cause excessive noise, which sometimes is forbidden in urban areas.

(3)After finishing work is completed, a certain length of time is required for curing which might cause delay of the subsequent construction program.

It is only natural that labor shortages are frequent due to the above mentioned problems, and such problems must be addressed. We have proceeded with the development aiming at :

(1)Improvement of working environment

(2)Labor saving

(3)Securing the quality

3. STAGES OF DEVELOPMENT

Table 1 shows the study of two feasible alternatives among those proposed prior to starting the manufacture of the experimental unit.

Alternative A is the system in which the finishing blades rotate around the traveling unit. Alternative B is the system where the finishing blades are arranged at the forward and rear ends of the traveling unit. Particularly, in the latter, it was anticipated that problems would arise especially in the steering of the traveling unit. Besides, it was found that the alternative A was superior to the other one in all respects including efficiency, weight and so forth. The decision was made to manufacture the experimental unit with this system.

Fig.2 shows the experimental unit. In this robot, the finishing is done by four blades rotating around the traveling unit while pressing down with a force in accordance with the hardness of the concrete.

As the result of the experiment, an accuracy equivalent to that of the skilled workers could be achieved and it was found feasible to develop a robot for practical use.

However, in the experimental unit the following problems remained unsolved and their solutions were badly needed :

(1) Failure to keep a straight course and meandering to one direction;

(2) In order to keep a straight course, different speeds are given to the motors on both sides. At that time plus when making a turn, peeling off of concrete occurs.

Fig.3 presents the modified experimental unit. For securing the straight course, it is modified to adopt the dual rotating system, where by the turning torques are canceled by turning the inner blades and the outer ones in opposite directions of each other. The result of the experiment after the modification showed substantial improvement in keeping the straight course, however the unit remained unsatisfactory in our opinion. This was because the difference in the torque caused by the difference between the radii of rotation of the outer blades and the inner blades remained, and it was not feasible to equalize the pressing of the outer blades and the inner blades. The solution to this problem was theoretically impossible, besides there were other problems in its stability and portability, which required a drastic modification. The present "the SURF ROBO" was born from the successful modification of this unit.

With regard to peeling off, effective improvement was achieved together with the modification for keeping a straight course. Furthermore, it was found from the results of test on the material and the shape of the caterpillar, it could be eliminated by wrapping porous sponge around the rubber caterpillar to which water was sprayed.

4. OUTLINE OF THE SURF ROBO

Photo 1 is the general view of the SURF ROBO and in Table 2, its specifications are shown. The SURF ROBO consists of the "main unit" , "control board" , "operation board" and "cord reel".

The SURF ROBO is a well-balanced robot that secures a straight line of travel with canceled torques, due to each set of 4 blades rotating around each caterpillar in an opposite direction, while pressing down with a force in accordance to the degree which the concrete is hardening. Its light weight (185Kg), ease of handling, and wireless remote control system are its major distinctive features.

4.1 Main Unit

Locomotion of the main unit is achieved by the use of 2 caterpillar-like drive units. Each drive unit can be controlled independently.

Fig.4 illustrates the method in which drive units can change direction. The main unit is lifted by way of the elevating motors and after turning the caterpillars by a require angle (usually 90°), it is replaced on the ground. Then , it travels by about 1.8 m taking the overlapping distance and the same process is repeated.

The R.P.M. of the blade, pressing force, angle of contact with the concrete surface, speed of traveling etc. are factors which effect the accuracy of finishing, and they can be raised and must be adjusted in accordance with the condition of the hardening concrete.

There are 8 blades total, 4 on each side with their speed ranging from 0~35 R.P.M. And the angle of the finishing blade can be adjusted at 3 different positions of 6, 8 and 10 degrees chosen in accordance with the hardness of concrete. The pressing force can be detected by the load sensors and adjusted so as to keep the pre-determined force by way of the blade elevating motors.

Around the main unit, the touch sensors are arranged to prevent it from collision with any projection or exposed butts of steel bars. The caterpillars are made of urethane rubber and wound with porous sponge tape.

This precaution is taken for the purpose of preventing possible peeling off of concrete when the caterpillars are elevated in making a turn when the concrete is not yet fully hardened. However, since it is difficult to fully prevent concrete from peeling off, the SURF ROBO is equiped with a sprayer to spray water on the caterpillars. It is possible to avoid peeling off by this equipment.

4.2 Control Board

The SURF ROBO's various motors are controlled through the control board, which stores programs for controlling the movement of the robot.

4.3 Radio Remote-Control Box

Fig. 5 illustrates the frontal view of the remote-control. Rotation of the blades, movement of the main unit, and adjustment of the contact pressure, are controled by wireless signals remotely. A weak wave of a 49 MHz band is used in the wireless station.

4.4 Self-Adjusting Cable Reel

The electric power cord (AC-200V) is attached to the reel (winding tension 7.8Kg) which automatically adjusts the length as the SURF ROBO moves.

4.5 Method of Operation

The SURF ROBO is normally operated automatically, although both automatic and manual operation is possible. The length and width dimensions of the area to be finished are input by way of digital switches in the control board and the choice of the starting direction (right or left) is made by a two-way switch. The SURF ROBO is designed that the whole area can be covered by a series of transversal passes which are automatically calculated by the robot's micro computer. The pattern of the SURF ROBO's coverage is shown in Fig. 6.

During the operation of the robot, there is virtually no need for the operator to intervene. If the robot should stray from its correct course due to slipping etc., the operator can easily re-correct it path by way of the balance switch.

5. SOME EXAMPLES OF THE SURF ROBO'S APPLICATION

In Table 3. the results of recent the SURF ROBO's application at actual construction sites are presented.

As the total area of concrete floor finished by the company exceeds 3 million m^2 , the effect of automation by the robot is substantial. In case of a large area like a factory floor, it is particularly powerful. The result of automatic finishing to the factory floor (Construction site A in Table 2) and the shopping center (Construction site B in the same Table) is stated hereunder;

5.1 Example of Application to the Factory Floor

Fig.7 is the rough plan of the factory.

The area finished in a day is normally $1200m^2$, perhaps $1500m^2$ at the most. However, since the construction was done in summer, these figures should be modified because of the quicker drying concrete. Prior to using the SURF ROBO, the following conditions were provided :

(1)Construction of the roof was completed first, to make work in rainy weather possible and prevent rapid hardening due to direct sunshine.

(2)Concrete was cast alternately to the areas of 6m×100m so that the SURF ROBO could easily be shifted.

(3)In order to maximize work efficiency, the trowel and the SURF ROBO were used simultaneously. But the final finishing is made by the SURF ROBO.

(4)A truck exclusively used for transportation of the SURF ROBO was provided.

As the result of following the previous procedure, this work was completed by 4 to 5 workers, while the same work in the summer season requires more than 10 workers.

Fig.8 shows the time chart of concrete floor finishing work, in which the whole area except for those areas close to the walls and pillars were finished with the trowel and the SURF ROBO. As shown in Fig. 9, the floor was finished with higher accuracy than that of manual finishing.

However, with respect to the irregularity made by the trowels on the finally finished surface, there is a large difference between the manual finish and the SURF ROBO finish which is shown in Fig. 10. The surface manually finished with the trowel is apt to present random patterns, while the surface finished with the SURF ROBO presents uniform geometrical patterns. In the case of the factory, the floor is finished with the addition of an anti-abrasion material such as color concrete to raise the abrasion resistance and dust proofness of the floor. When the floor is colored with an anti-abrasion material, the pattern left on the floor after finishing becomes more conspicuous. Therefore the decision is up to client. But with regard to accuracy, there will be no problem, because the error of the finished surface is below 0.05mm in either case.

5.2 Example of Application to the Shopping Center

Fig.11 shows the plan of construction site B from Table 3. This building is a shopping center. Its floor is covered with polyvinyl chloride floor tiles. This is an example of a comparatively large scale project in which the area of concrete floor finishing per day reaches around 1,500 m^2. As shown in Fig. 11, the site is suitable for construction by the robot because there are very few openings and partitions except for a large number of pillars.

Prior to using the robot on this job site, a messenger wire is laid over the center line of the area to be finished as shown in Fig. 11. The cable reel itself slides along the messenger wire. In so doing, the cable reel slides along the length-wise direction together with the SURF ROBO as it moves, extending the cable width-ways. Photo 2 and Fig. 12 show actual operation of the robot system. In case of the office buildings, finishing work can be done as if there were no power source cable by using this system.

At the shopping center construction site, the work was completed by 2 to 3 workers. 5 to 7 workers must be placed in another system. The accuracy of finishing was quite satisfactory as shown in Fig. 9.

6. CONCLUSIONS

In using the SURF ROBO concrete floor finishing robot, workers were able to work very efficiently and easily. Now, our company has been using about 10 of the SURF ROBOs at practical construction sites. The finishing area of about 200,000m^2 has been attained by the SURF ROBO.

But the SURF ROBO has yet some technological problems to be solved and items to be noted when the robot is used:

(1) We can not reduce concrete floor finishing time when using the SURF ROBO.
(2) It is necessary to lighten and compact the SURF ROBO.
(3) We have to educate the plasterers about operating and maintenance of the SURF ROBO .
(4) Some conditions at the construction sites need to be changed for the SURF ROBO's finishing work.

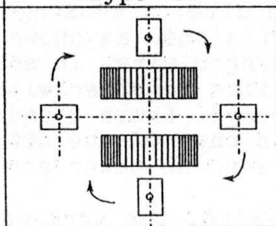
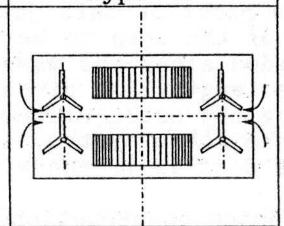
To reduce concrete floor finishing time we have been developing the dehydration ROBO as shown in Fig.13.

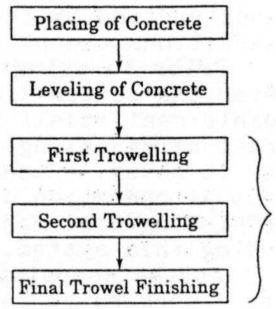
The authors hope that the SURF ROBO will be one of the methods to solve the problems of "labor shortage" and "aging Workers" in the construction industry.

7. ACKNOWLEDGEMENTS

We would like to express our appreciation to Mr.Shigeru Yamada, Mr.Mitsutoshi Torikai and Mr.Toru Shimano for their development work.

Table 1 : Evalution of Plans

Item	Type A		Type B	
Plan				
Finishing Work Capabirity	100 m²/h	○	50 m²/h	△
Weight	80 kg	○	100 kg	△
Method of Turnning	Lift up of Main Unit	○	Pivot Turn	△
Evalution	○		△	



*Robotization

Fig. 1 : Concrete Floor Finishing Process

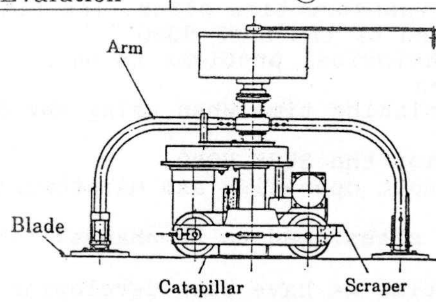


Fig. 2 : The Experimental Unit

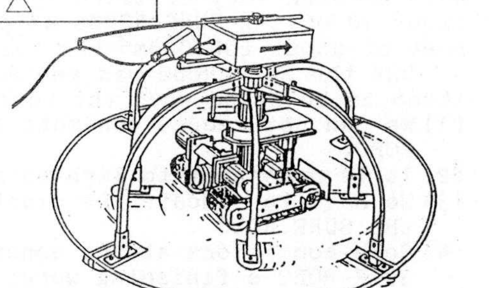
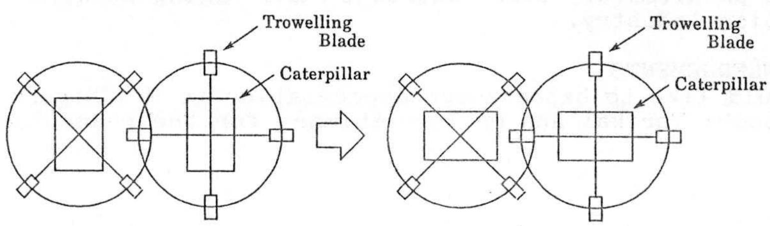


Fig. 3 : The Modified Experimental Unit



(a) before Turning (b) after Turning

Fig. 4 : Turning of the SURF ROBO

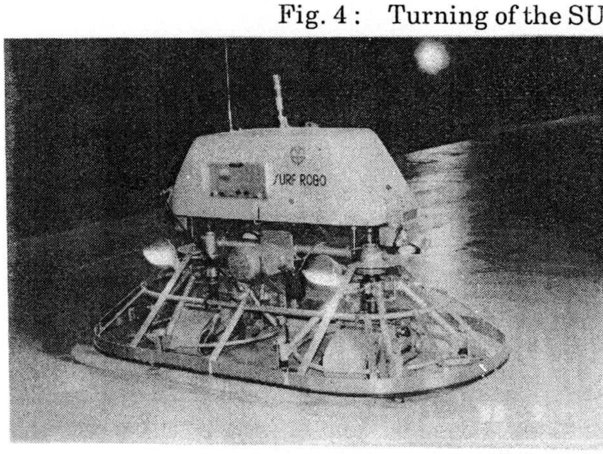


Table 2 : Specifications of the SURF ROBO

Model	TSCP-2000
Measurement (L×W×H)	2230×1260×1350mm
Weight	185 kg
Contact Pressure at Trowelling	0.12 kg/cm²
Finishing Work Capability	300 m²/H (at two step finishing)
Standard Run Way Width for Finishing	2140 mm
Rotation Speed of Blades	0~35 r.p.m
Travelling Speed	0~12 m/min
Operation	Radio Control and Microprocessor Control

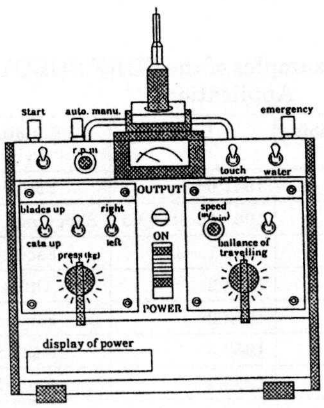


Fig. 5 : The Front View of Remote-Control

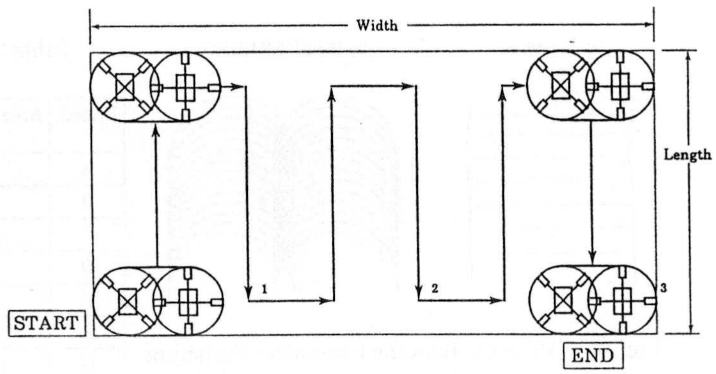


Fig. 6 : Travelling Pattern of the SURF ROBO

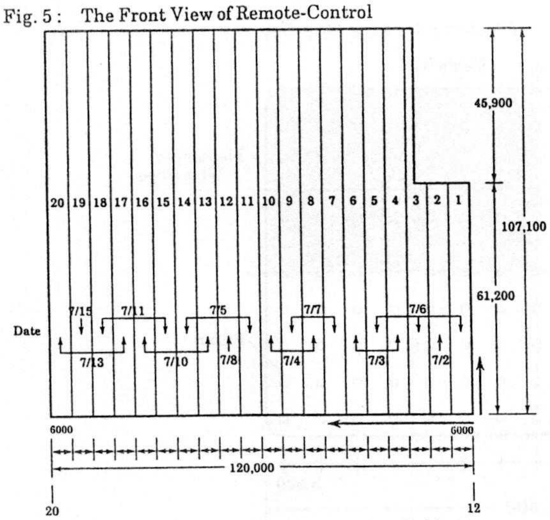


Fig. 7 : Plan of the Factory (Project A in Table 3)

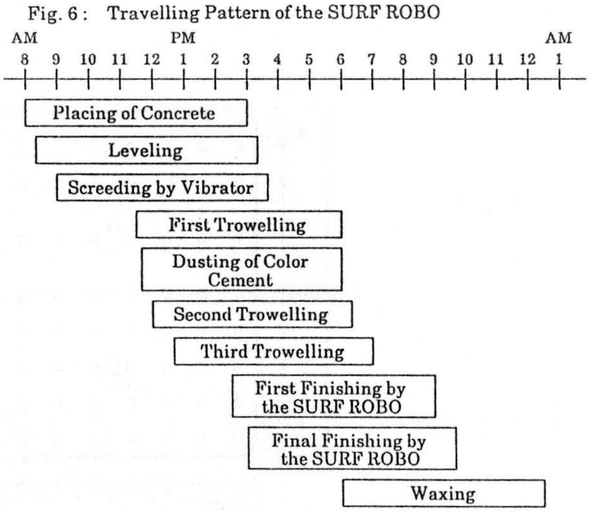


Fig. 8 : Time Chart of Concrete Floor Finishing Work at the Factory (Project A in Table 3)

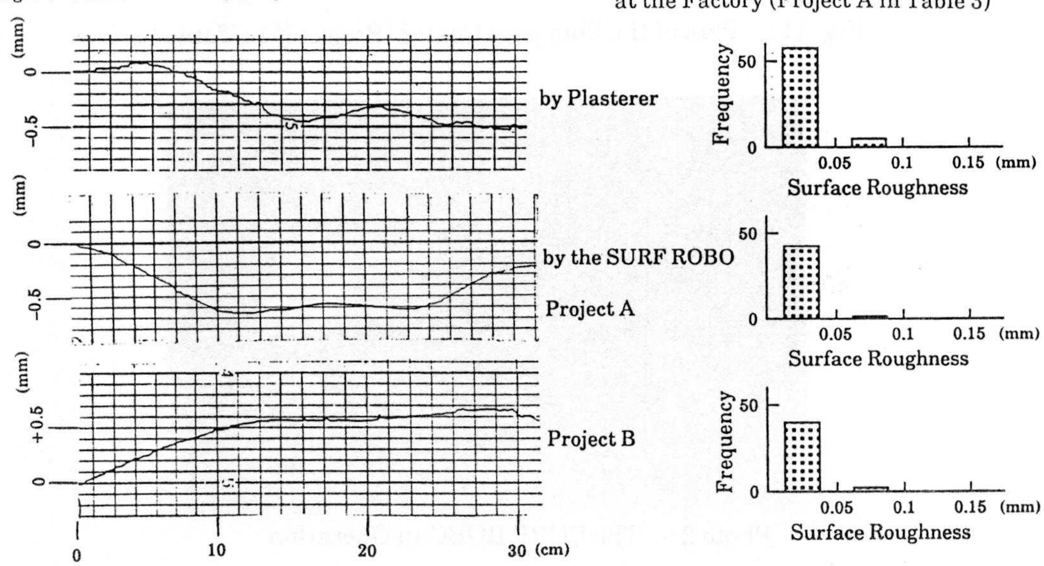


Fig. 9 : Accuracy of Surface after Finishing

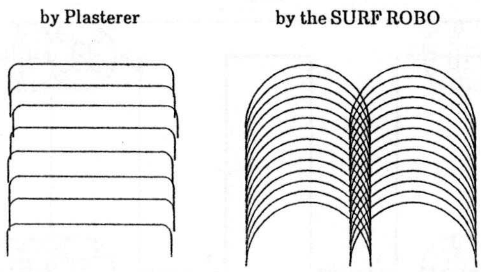


Fig. 10 : Prints Left on the Floor after Finishing

Table 3 : Examples of the SURF ROBO's Application

Project	Area of Finishing (m^2)	Date	Building Type
A	12,000	1987.6~7	Factory
B	24,000	1987.12~1988.3	Shopping Center
C	30,000	1988.1.~3	Factory
D	7,000	1988.2	Office
E	69,000	1988.2~4	Factory
F	10,000	1988.3	Factory
G	130,000	1988.4	Shopping Center

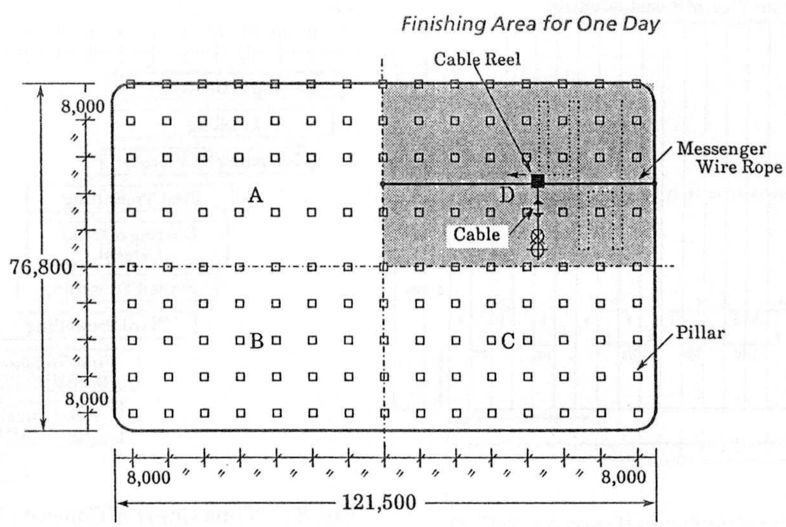


Fig. 11 : Plan of the Shopping Center (Project B in Table 3)

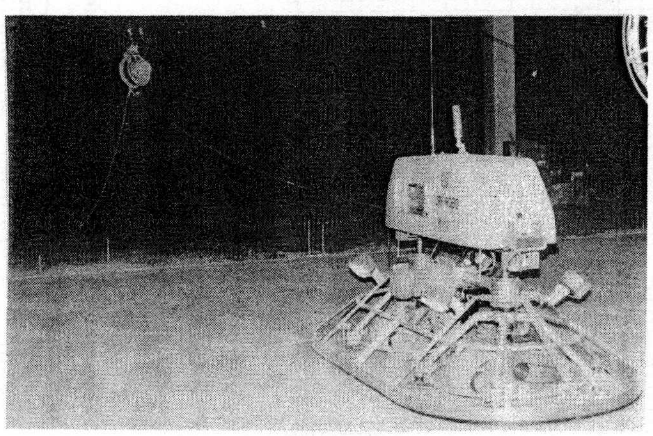


Photo 2 : The SURF ROBO in Operation

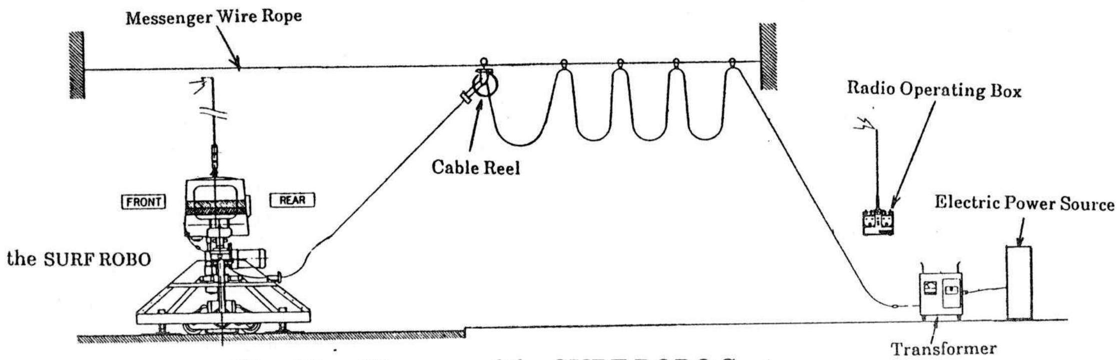


Fig. 12 : Diagram of the SURF ROBO System

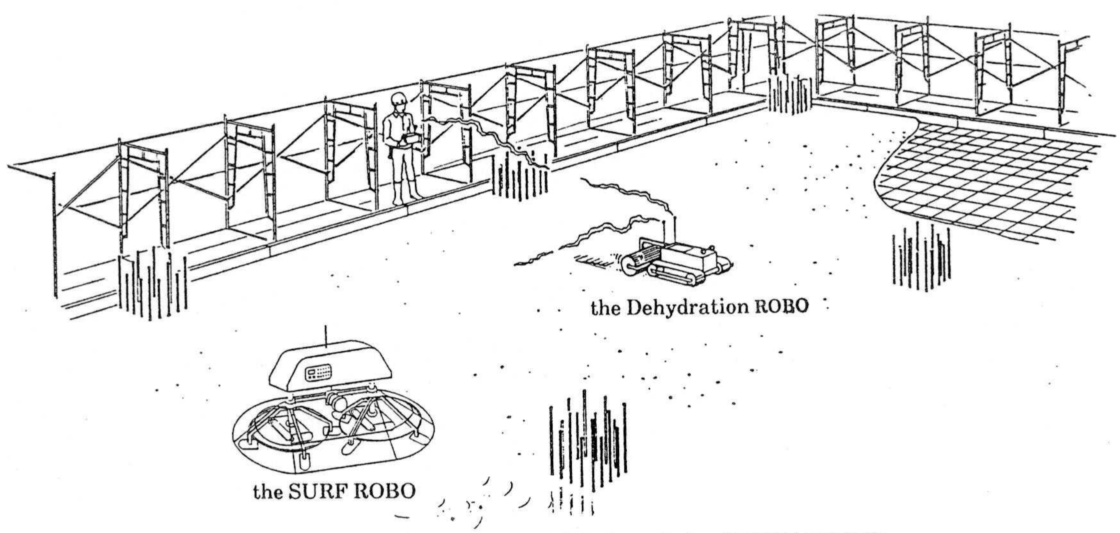


Fig. 13 : The Dehydration ROBO and the SURF ROBO