THE DEVELOPMENT OF A NEW REINFORCED CONCRETE WORK SYSTEM THROUGH THE APPLICATION OF THE ROBOT MODULE CONCEPT
—— WASCOR Research Project Report(Part 2) ——

1) Yukio Hasegawa, 2) Nobuhiro Okuyama, 3) Haruo Hoshino,
4) Tohru Shinozaki, 5) Ryoji Yoshitake, 6) Shinji Yamashita,
7) Hiroshi Asano, 8) Tatsuo Kobayashi, 9) Kinya Tamaki
Member, WASCOR Research Project

System Sciense Institute, Waseda University
3-4-1 Okubo, Shinjuku-ku, Tokyo
169,Japan

Abstract

In this paper, a system which employs robots in the automation of construction work is proposed. Specifically, the methodology of a robotized system design in reinforced concrete work are described. Reinforced concrete work involves various works such as mold and reinforcement assembly, concrete placement, straight finish, and mold demolition. The complexity of this work process has been the major obstacle to develop the robotized system. It has been considered difficult to use robots in construction work under the present conditions. Therefore, the development of a drastically reformed construction system was required. In order to accomplish the robotized system for this complex construction work, a consistent system design approach was taken. This approach ranged over a total system design including structural design and construction method design, through the design of many types of robots for use in this system. A new robot modularization was developed, and our own design technology was created.

1.Introduction

At present, reinforced concrete work involves various works such as assembly of reinforcement and molds, concrete placement, and demolition and removal of molds. Because of the complexity of this work process, concrete work must be carried out largely by hand. It has always been considered difficult for robots to do this work. Therefore, it was necessary to develop a new construction system based on a structural design and construction method which are adequate for robots.

In this study, a consistent system approach was followed from a total system design including structural design and construction method design to detailed system design including designs of various robots. In connection with this, the following three points were singled out for discussion: 1) the structural design and the construction method design appropriate for the utilization of robots, 2) the development of a robotized construction system and the design concept for each robot used in this system, and 3) the development of "modular" type robots.

In designing this system, the construction of a standard office building was assumed as the project. The feature of this building is described in WASCOR Research Project Report (Part 1).

2. The Design of a Robotized Reinforced Concrete Construction System

An overview of the design system is shown in Fig.1. The robotized reinforced concrete construction system consists of eight types of devices, robots and peripheral equipment. The development of this system was carried out using the consistent system approach in consideration of the present level of construction and robot technology.

The developmental scope of this system ranged from the feasible structural design and construction method design suited to the utilization of robots, to the design of hardware to enable robots to carry out construction work. In the process of the system approach, the concept of a total system was first created. This total system includes structural design and construction method. After the total system was designed, this system was divided into subsystems and tertiary systems. And detailed robotized system was designed through this system design method. An example of the design process for a mold assembly system is shown in Fig.2. The contents of the design are described as follows.

1) The Design of a Construction Method Which is Suited for Robots

A broad outline of the structural design and construction method is shown in Table 1. This was designed on the assumption that the building was a composite structure. Basic principles of the structure design and the construction method design were that together they should form a technically rational system under which robots can work effectively and be applied easily to a site. The following expresses the considerations concerning the construction method.

(a) The Elimination of On-Site Reinforcement Assembly Work.

It is too difficult for robot to guarantee precision assembly on site reinforcement work, because reinforcement is easy to bend. Therefore, reinforcement is preassembled to steel beams, floor panels and so on. Robots are not used in reinforcement work on site.

(b) The Change of the Concreting Process

When concrete is distributed by an externally placed concrete pump, a large area is needed for distribution work, and moving from stage to stage is time consuming. In order to reduce the size of the working area and simplify movement from stage to stage, it was decided to use a robot which was able to move about on the floor. However, it was difficult for the a robot to move on the floor laid reinforcement befor concreting.

In order to achieve the necessary floor, the concrete placement process was changed. The new concrete placement process is explained in the next "3) Robotized Work System in Reinforced Concrete Construction"

(c) The Design of Connection Brackets of the Half Precast Wall Panels

Connection brackets of the half precast wall panels for assembling of external walls were designed to make connection easy. Robots can do this work with only two actions for these brackets.

(d) Structural Design of Mold Components

The structure of a mold is shown in Fig. 3. The farmework of the components is made of aluminum preciously. A vertical batter (Fig. 4) was designed as a kind of device which incorporated a mechanism that simplified assembly. This has made it possible for a robot to easily assemble molds.

2) The Grouping of Work Functions and the Assignment of Function to the Various Robots

Construction work through the study of a structural design and construction method is divided into 13 work functions as shown in Fig.5. If a differrent type of robot was used to perform each individual function it was feared that problems would occur in terms of cost and in securing places to manage the robots, because a robot capable of doing only one specialized task would not be in use for long periods.

Therefore, it was necessary to standardize the structure of the robots to the highest degree possible in order to reduce the number and variety of robots and increase their operating time. The way of the standerdizing is first work functions are grouped and next the groupes of work fanctions are assigned to robots. The follwoing four items were pointed out as the main factors to be considered in grouping the work functions.

(a) Similarity of motion patterns of each compornent
(b) Similarity of conditions of work sites
(c) Similarity in the shape and the work load of components
(d) Connection of work processes (Process do not overlap)

Fig. 5 shows that each of the 13 work functions fall into one of six categories grouped according to the criteria above. One robot has been assigned to each category.

A fixed robot was assigned exclusively for each work functions in the vertical and horizontal conveyance and fitting of half precast wall panels. And two modular type robots for light and heavy-duty works were assigned for other groups of work functions. The two robots were designed by applying the modularization concept which is described in the next chapter. Fig. 9 shows a modular light-duty robot. Fig. 6 shows a heavy-duty robot.

3) Robot Work Systems in Reinforced Concrete Construction

Fig. 1 shows the entire outline of the robotized construction system which resulted from this study. As shown in Fig. 7, the time period of six days including time curing concrete was established for the completion of the process of constructing the floor in a building frame under the robotized system and for shortening the duration of reinforced concrete work to the highest degree possibe. This process for reinforced concrete work was repeated on each consecutive floor.

Fig. 8 shows the progress of work on a given floor. As shown in Fig. 8a, the half precast panels for external walls are fitted, and molds are assembled by a light-duty robot. Then a heavy-duty robot fits floor members in Work Zone A on the floor above. Next, concrete is placed in Work Zone A as shown in Fig. 8b.

Because the work area is divided into external (A Zone) sections, and internal (B Zone) sections, the arm of a heavy-duty robot can be short. At the same time, mold demolition is carried out by a light-duty robot. The same process is carried out in B zone. As shown in Fig.8c, concrete is placed from the same floor.

3. The Development of a Modular Light-Duty Robot

This paper deals with a robotized mold assembly system and describes the development of a modular light-duty robot. The technique of robot modularization which was described in the previous paper (WASCOR Research Project Report: part 1) was applied in the development dealt with here.

In applying the robot modularization technique to the assembly system, it was considered that the objects, environment, and methods for the assembly work were standardized to the highest degree possible in order to simplify the introduction of modularization.

Robot hardware modules (end effector, wrist, arm, body, and locomotion modules), which are the structural elements of the modular light-duty robot, were designed. Fig. 9 shows the hardware modules of the light-duty robot and also the peripheral machinery. The following expresses the design process of the modular light-duty robot by adopting as examples an arm module and a wrist module, the framework of the robot.

1) Task Description of a Mold Assembly System Using a Robot

Motion trajectories of work pieces are described by the three pieces of data using in mold assmbly system : the object, the environment, and the work method. The motion trajectories should be prescribed by each sheathing plate, vertical batter, and horizontal batter, at each assembly placement.

Then the motion trajectories prescribed for the work pieces are changed to the trajectories required for the light-duty robot. The changed trajectories are called required-motion trajectories.

Furthermore, a required-workspace where the required-motion trajectory is added by the motion range of the robot is specified.

The framework of the modular light-duty robot is established by selecting the arm module and the wrist module which satisfy all the required-motion trajectories according to the task description. The length of each link and the moving range of each joint of the robot are obtained from data concerning thè required-workspace on the established robot framework.

2) The Production of Lists Regarding Arm Modules and Wrist Modules

Three degrees of freedom in positioning function are allotted to the arm module and two or three degrees in orienting function are allotted to the wrist module. The capabilities of each type of module are exhaustively enumerated.

Modules with ineffective capabilities are excluded from the enumerated alternatives and the lists of arm modules and wrist modules are provided accordingly. One hundred types of modules appear in the arm module list and thirteen types appear in the wrist module list.

3) The Selection of an Arm Module and a Wrist Module

The required-motion trajectories prescribed previously constitute translation motion and rotation motion. Firstly, the appropriate arm module which can achieve all the translation motions involved in the required-motion trajectories is selected from the arm module list.

Secondly, the suitable wrist module capable of all the rotation motions involved in the trajectories is selected from the wrist module list after consideration of its compatibility with the arm that has been selected. Through this process, the arm and the wrist modules are combined to form the framework of a modular light-duty robot.

In this way, the arm module and the wrist module which assemble three different workpieces, such as sheathing plates, vertical batters, and horizontal batters are obtained. The mold assembly process can be carried out by one modular light-duty robot by means of changing three types of end effector modules which are designed to grasp the sheathing plates, and vertical and horizontal batters.

4. Conclusion

A consistent system design approach was applied for the development of the robotized reinforced concrete work system. Through this study, it was confirmed the modular type robot made a great contribution to realize the robotized system. Thus, highly automated and labor-saving construction system incorporating robots was designed.

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Member, WASCOR Research Project:

1), 8), 9) Waseda University; 2) Shimizu Corporation; 3) Takenaka Corporation; 4) Toda Construction Co. Ltd.; 5) Fujita Corporation; 6) Sato Kogyo Co. Ltd. ; 7) Komatsu Ltd.

Table.1 Outline of The Structural Design and The Construction Method

Building Component / System	Column	Girder, Beam	Wall	Floor
Reinforcement Work System	Reinforcement Unit is Preassembled to a Steel Column	Reinforcement Unit is Preassembled to an External Girder Steel Frame Internal Girders and Beams Have Steel Structure	Reinforcement Unit is Preassembled on Half Precast Panel	Reinforcement Unit is Preassembled on Sheet Steel Mold
Mold Work System	Mold Parts are Assembled on a Work Site	Mold Parts for External Girder are Assembled on a Work Site	Mold Made of Half Precast Panel is Used for the Extenal Surface of the Wall Mold Parts for the Internal Surface of the External Wall are Assembled on a Work Site	Mold Made of Sheet Steel is Assembled on a Work Site
Concrete Work System	Concrete is Always Placed on Work Site			

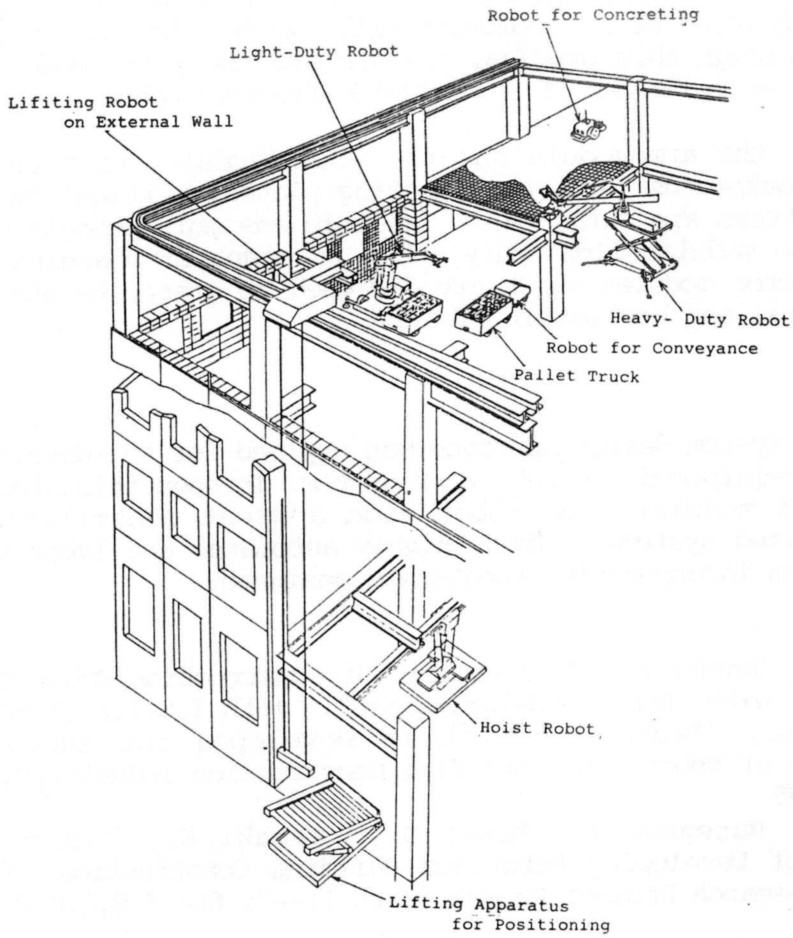

Fig. 1 Imaginary Plan of The Robotized Reinforced Concrete Work System

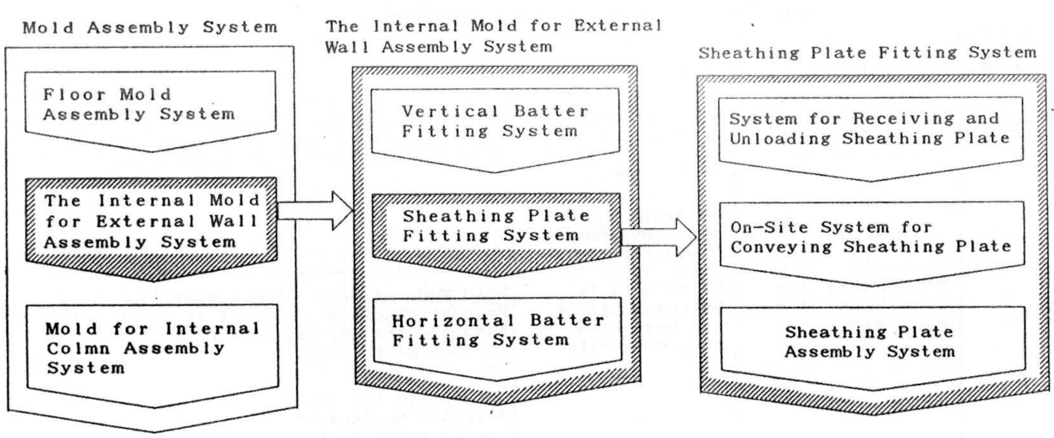

Fig. 2 System Design Process

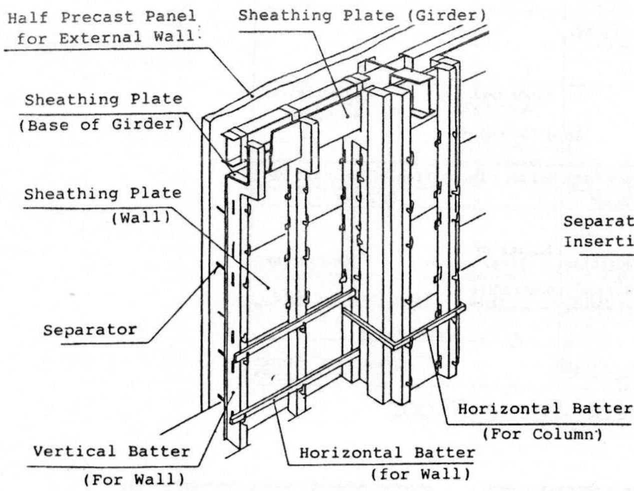

Fig. 3 Aerial View of Mold Assembly

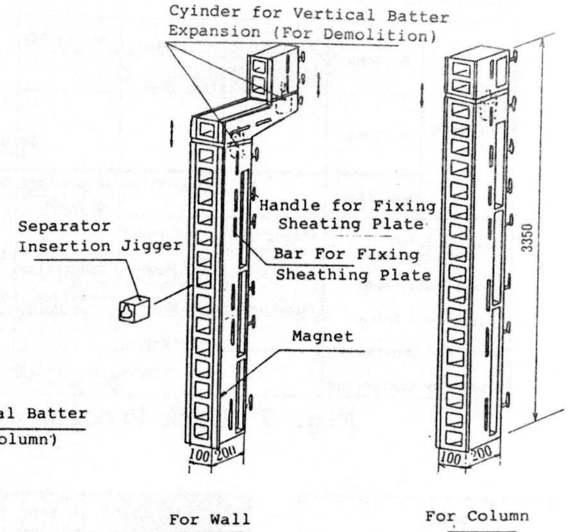

Fig. 4 Basic Structure of Vertical Batter

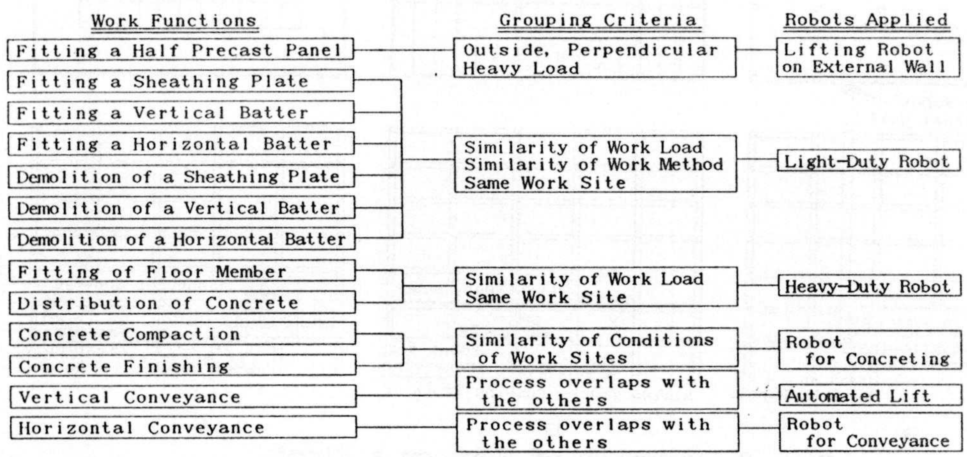

Fig. 5 Grouping of Work Functions and Assignment of Tasks to Robots

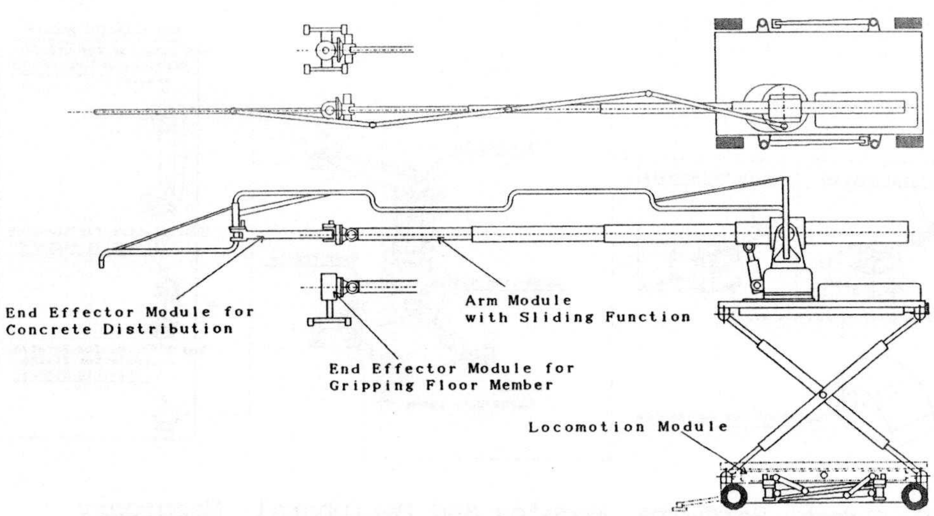

Fig. 6 Heavy-Duty Robot

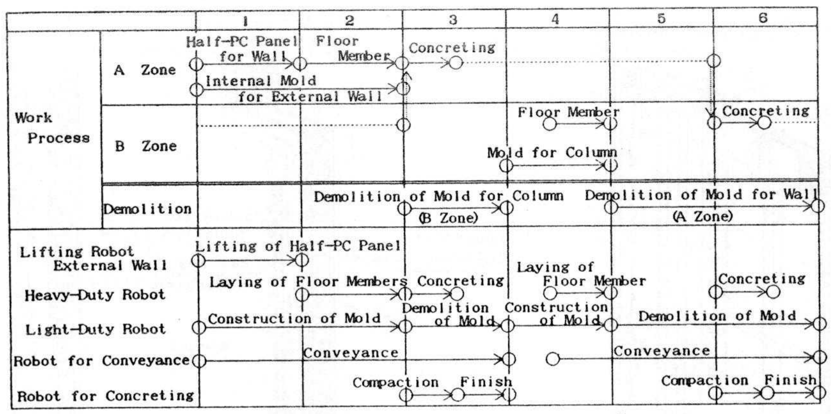

Fig. 7 Work Process for a Floor

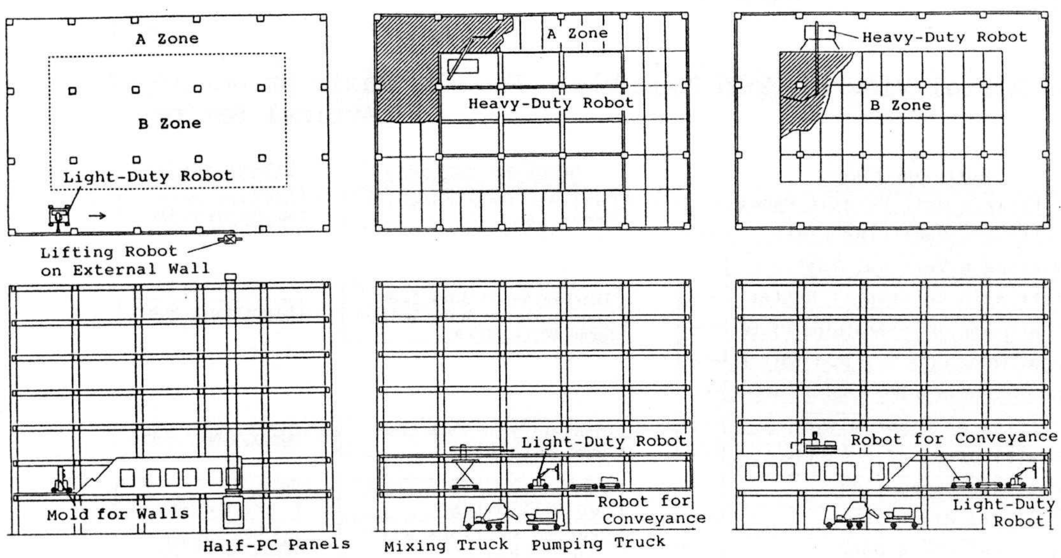

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Fig. 8 Progress of Work on a Floor

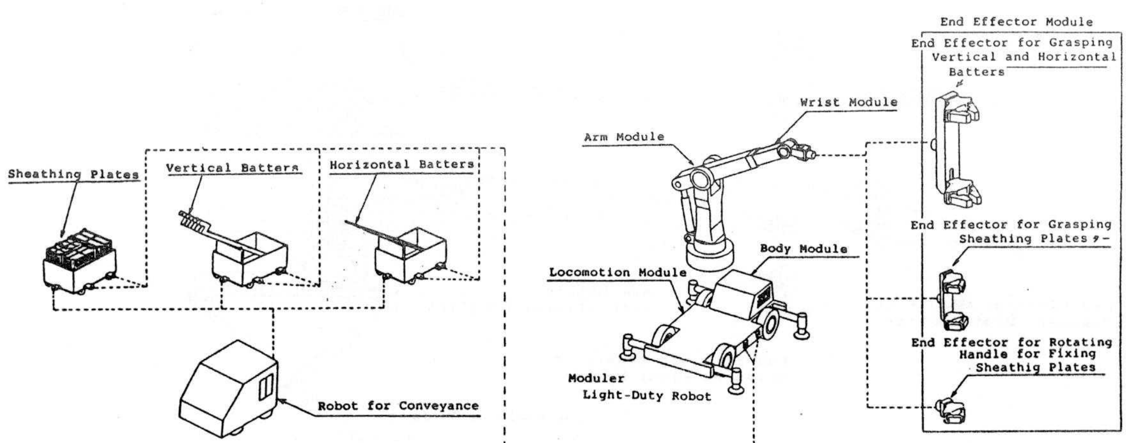

Fig. 9 Robot Hardware Modules and Peripheral Machinery Involved in Modular Light-Duty Robot System