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A ROBOTIZED WALL ERECTION SYSTEM WITH SOLID COMPONENTS

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ABSTRACT

One idea for the step up of robotization in building construction, is to change the conventional construction works adaptable to robotics. In this paper, a structural system for the wall erection named SMAS (Solid Material Assembly System) is proposed and the developed hardware system are mentioned.

SMAS is a kind of reinforced masonry construction system. A standard building component of this system, 30cmx30cmx18cm in size and 20kg in weight, is made of pre-cast concrete and includes cross-shaped steel bar inside of each component for the reinforcement of structural wall.

Components are positioned automatically by the robot one by one without arrangements of conventional bonding. Following the positioning of each components, steel bars are connected to those of adjacent components also by the robot. The joint type of steel bar for vertical direction is mechanical, and that for lateral direction is overlapping. Concrete is grouted from the top of the wall which is erected one story high (about 3m).

The newly developed operating hand is installed to the mother robot, 6-articulation-type robot which was developed for wide variety of applications in factory use and a series of experiments for wall erection were carried out.

1. Introduction

The electronic technology has rapidly progressed in recent years, and related new technologies of all kinds have been applied in the industrial world and thus have changed circumstances in production activities.

This trend is not exceptional also for the building industry. New technologies have been introduced in the building industry such as 1)computer aided designing, drafting and cost-estimating for a designing stage, 2)process management using a personal computer and various construction robots for a constructing stage, and 3)computer controlled facilities management for a maintaining stage.

Great effort is also put on the consolidation of a data base at each building stage.

One of the research projects for development of construction technologies supported by the Ministry of Construction, "Development of an Advanced Construction Technology by Applying the Electronic Technology", was carried out through 1983 to 1987.

One of the subjects in this Project is a development of a building construction robot. The fruit obtained in the subject is briefly introduced in this paper.

2. Back ground

The introduction of robots into building construction field are generally considered for, 1) improvement on building productivity (efficiency, labor-saving), 2) improvement on quality of buildings, 3) improvement on labor circumstances by providing robots for dangerous works or physically hard works which have been done by human beings, and for 4) response to the expected lack of the skilled labor and the advancement of labor age in the future.

On the other hand, there are some problems, which are considered to be inherent in the building industry, and to be solved to realize building construction by robots. Those are:

(1) There is few repetitional works in the building construction field, which are favorable for robots.
(2) There are various kind of working processes and few continuities among them.

There are also miscellaneous work processes in which worker's role is not clearly described, and therefore, it is hard to apply robots in the process.

(3) A construction robot must be light weight as much as possible and at the same time, is required to handle heavy things.
(4) A construction robot must move from place to place in the construction site where many obstacles are expected to be.
(5) The circumstances in the construction site generally have severe conditions for robots.

The construction robots, however, have been increasing in number and are expected to do furthermore hereafter, even if there are many difficulties in the building industry as mentioned above. Looking at existing robots in the building construction field, many of those are limited to the robot without supplying materials, such as the robot for concrete floor finishing and for sensing tile exfoliation, or the robot with using fluid material such as the robot for distributing concrete and for spraying refractory coating materials.

According to the analyses described above, the robot to be developed under the research project was focused on the one for assembling solid structural components, since this is thought to bring a tremendous versatility to the field of construction.

3. Robot-oriented construction system and structural design

The rapid progress being achieved today in the modernization and industrialization of building construction technology has triggered a trend to reduce the complicate works at construction site and to increasingly produce building components at factories. It is obvious that the prefabrication has been successful in up-grading the quality of the building and in shortening the construction period. The sizes of those building components such as prefabricated structural members are also becoming larger to simplify assembling work at the construction site.

However, these movements are not necessarily oriented toward the introduction of robots. The heavy and large components are difficult to be operated by the robots and the complicated assemble techniques are sometimes too skillful for robots. Meanwhile, when one looks at the prefabrication of compact and lightweight structural components as a means of accomplishing construction work more efficiently, robots can be used for assembling these structural members efficiently.

From this point of view, a kind of masonry structural system was developed and proposed as a robot-oriented construction system, and named SMAS(Solid Material Assembly System). A masonry structure has not been considered as a major structural system in Japan because of earthquake problems, however, it becomes to be recognized as a flexible structural system applied to various building designs when properly reinforced. In addition, it has advantages in the construction cost and in the construction period.

The characteristics of this system are mentioned below.

(1) The basic solid component that is stacked and composes structural walls, is made of pre-cast, 30 x 30 x 18 cm in size and weigh about 20 kg.

(2) The solid components are stacked by the robot without filling mortal for bonding at their joints either vertical or lateral.

(3) For the reinforcement of the structural wall, the cross-shaped steel bars are fixed to each components and joined to each other by the robot when components are stacked. The robot grasps this steel fixtures and move the components to the designated position.

(4) The vertical joint is a screw-type mechanical joint and the lateral one is an over-lap type joint.

(5) After the solid components are assembled, concrete grout is poured from the top of the wall and the components are filled with grout to comprise a wall of monolithic assembly.

(6) The foundation of the wall is cast-in-place concrete and floor may be made of wood, pre-cast concrete panels, cast-in-place concrete or others.

A basic solid component is shown in Figure 1. Figure 2 shows the layout of steel bars for the reinforcement and Figure 3 shows the components-stacked wall. For the verification of adequacy of the proposed over-lap type joint in lateral direction, wall specimens were made and the horizontal loading test was carried out. The result shows that the strength of the proposed joint is comparable to the ordinal lap-joint, when properly designed.

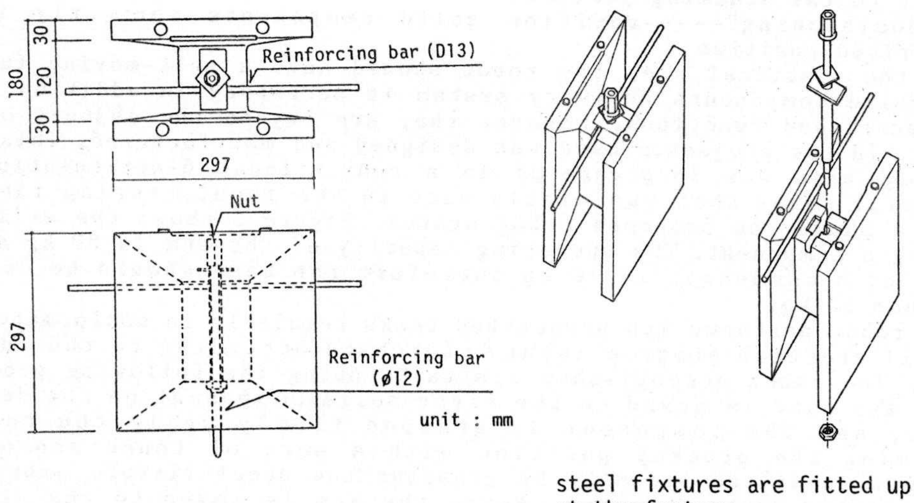

Fig. 1 Basic Solid Component

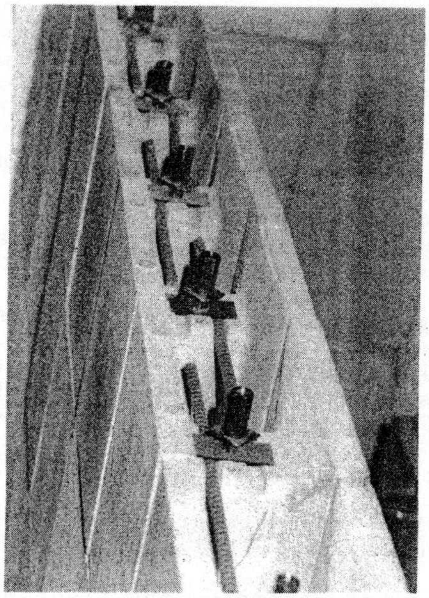

Fig. 2 Over-lapped Steel Bars for the Reinforcement

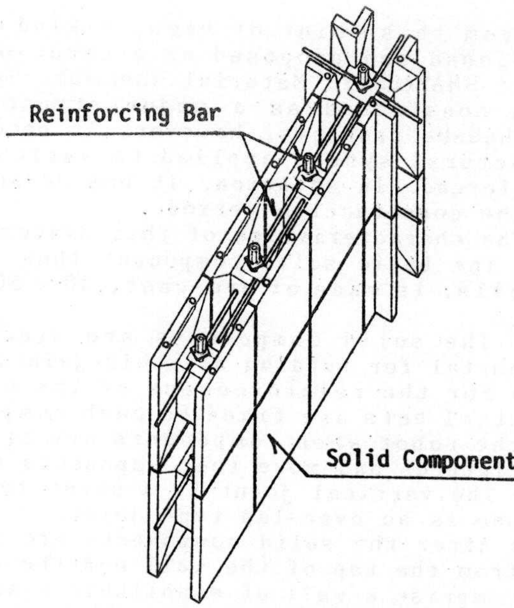

Fig. 3 Overview of Stacked Wall

4. Robot system for assembling solid components

The robot system essentially consists of an arm , a hand and a control system.
The hand has following functions;
(1) "grasping"--------grasp and release solid components
(2) "jointing"--------joint screw-type joints in the vertical direction
The arm has following functions;
(3) "transporting"----transport solid components from the delivery pallet to the stacking position
(4) "positioning"-----position solid components correctly in the prescribed position

For the practical use, the robot should have a self-moving function and a solid components delivery system is necessary in addition to the above mentioned functions, however they are beyond the objects of this project. In the project,a hand was designed and manufactured. This newly developed hand was incorporated in a conventional 6-articulation-type industrial robot that was widely used in the manufacturing industry. Figure 4 shows the proposed robot system. Figure 5 shows the wrist hand grasping a component. The operating capacity of the arm is 80 kg and the weight of a component is 20 kg therefore the hand should be designed less than 60 kg.

The robot performs its prescribed tasks regularly in conformance with the wall erection program input beforehand according to the building design. The robot accomplishes its tasks using the following procedure. First, its hand is moved to the first solid component on the delivery pallet, and the component is grasped firmly while the robot is confirming the stocked position with a sort of touch sensor. The component is lifted steadily by grasping the steel fixture embedded in the center of the component. Next, the arm is moved to the stacking position and lays the component onto its prescribed position. The robot then searches for a screwing point and tightens the screw to secure the component firmly.

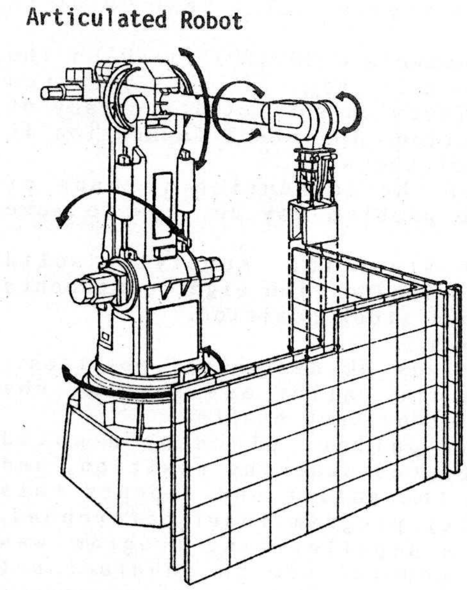

Fig. 4 Proposed Robotized Wall Erection System

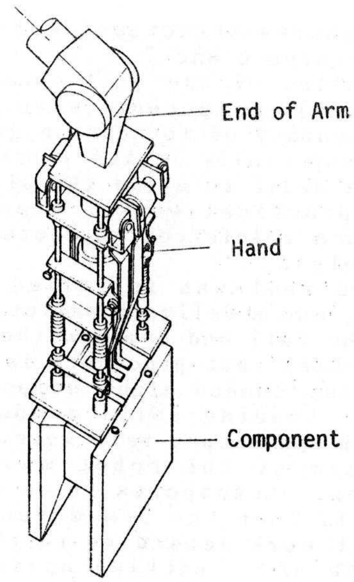

Fig. 5 Detail of Hand

5. Outline of wall erection tests by robot

To investigate the possibilities of robotization in SMAS(Solid Material Assembly System), some executing tests were carried out.

In the future, the robot will move by itself, calculating its position according to the prescribed program, stack solid components on the designated position and erect a structural wall with a required accuracy. And solid components will be supplied automatically for the assembly robot.

In this test, a 6-articulation-type robot which was used for manufacturing industries was fixed on test floor and the newly developed hand was installed to this robot. The robot was planned to

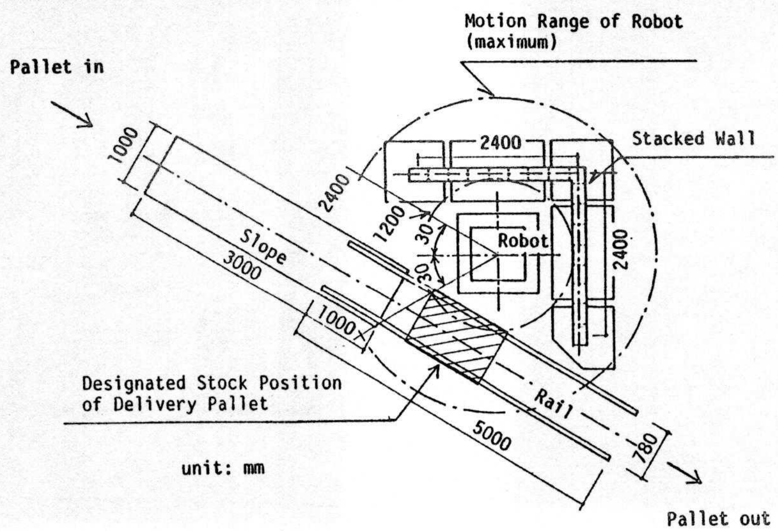

Fig. 6 Layout of Test Floor

elect a L-shaped structural wall shown in Figure 4. The test setup is shown in Figures 6 and 7.

A foundation of the wall was steel channels(C-200x80) fixed on the floor and solid components were stacked on it.(Fig. 7) It is expected that the accuracy of foundation greatly effects on the total accuracy of the wall, especially in its vertical direction. The steel foundation is selected in order to avoid the distortion of the wall.

In the practical works, almost all of the foundation is made of cast-in-place reinforced concrete, and the problem may be how to make it accurately .

A sloped rail was installed on test floor for supplying solid components, and a delivery pallet which was loaded with eight components moved on the rail and came to the prescribed stock position.

The stacking test procedure is as follows.

(1) A pallet loaded eight components arrives at designated position. (Fig. 8) Loading solid components on the pallet and setting the pallet on the sloped rail were carried out by test staffs.

(2) The arm of the robot moves to the pallet, picks up a solid component, transports it to the designated stacking position, and stacks it. Then the arm moves back to the pallet and repeats this series of work according to the computer program input beforehand. In a work of picking up in order, a depalletizing program was used, that has been developed for general use in manufactural factories. The robot moves automatically according to this program when the operator teaches some critical points for positioning. When the hand reaches closely to the next component on the pallet, the claws of the hand begins to grasp the steel fixture embedded in the component, with the signal from the optical sensor. Synchronously, the nut-runner installed in the hand gears with a nut that is fixed to the top-end of vertical reinforcing bar. (Fig. 9)

(3) Motions of the robot are controlled by computer. Approaching to the stacking position, the arm of the robot moves in high speed to close the position(10cm side, 10cm above from the previously stacked

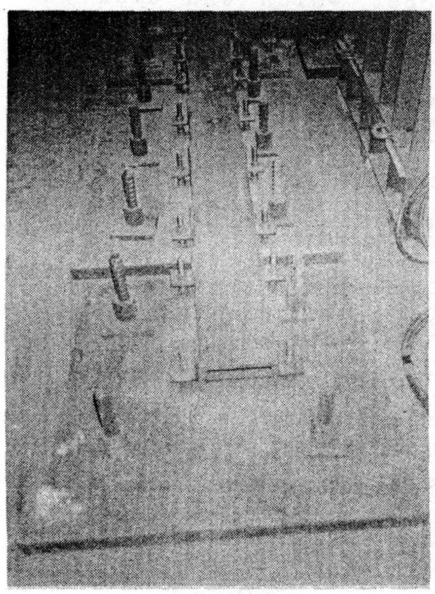

Fig. 7 Steel Foundation Fixed to Floor

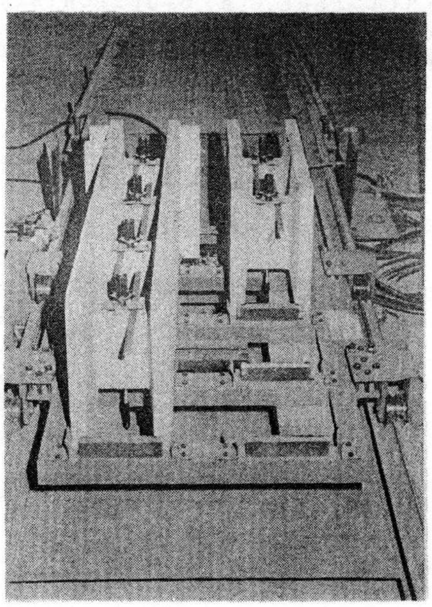

Fig. 8 Solid Components on Delivery Pallet

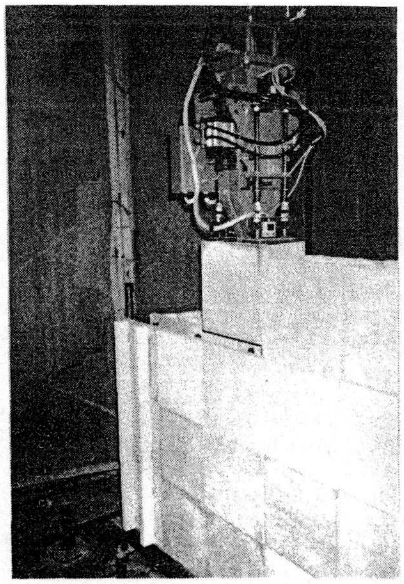

Fig. 9 Picking up Solid Component

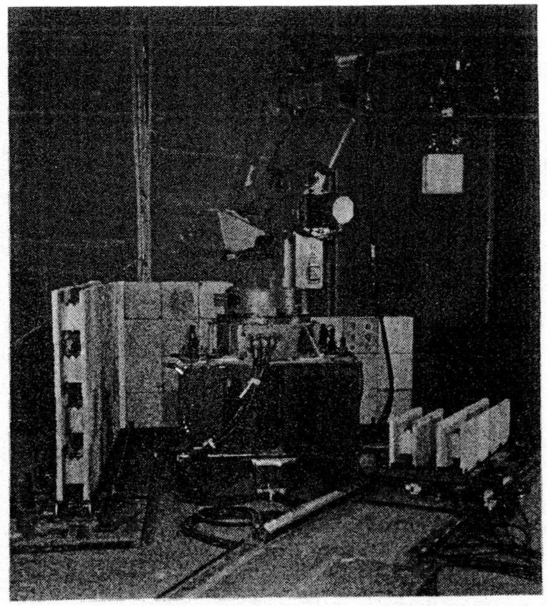

Fig. 10 Transporting to Prescribed Position

component), then slides slowly to the designated position. (Figures 10 and 11) After the robot releases and stacks the solid components on the designated position, it begins to screw a bolt of vertical reinforcing bar into a nut of the under-laid component.

(4) When the pallet becomes empty, it is automatically kicked out and the next pallet is supplied.

These continuous actions are repeated, and finally a L-shaped structural wall 5.2m long with a height of 2.1m was constructed with 17 x 7 solid components. (Fig. 12)

It takes almost one minute from picking up a solid component till stacking it.

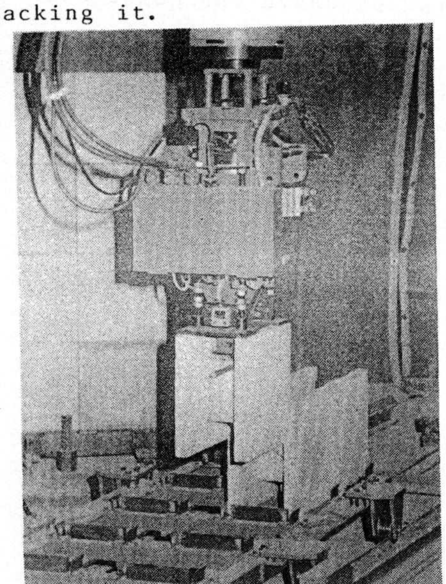

Fig. 11 Stacking and then Jointing

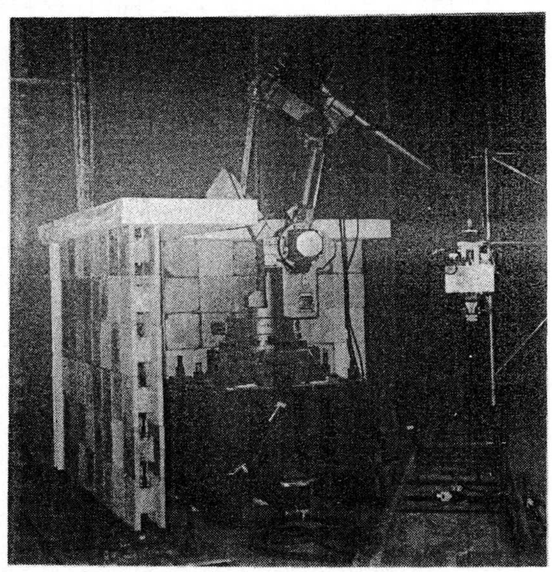

Fig. 12 Elected L-shaped Structural Wall

6. Concluding remarks

The major findings drawn from the test are summarized below.

(1)In the conventional masonry works, size errors of components are absorbed at the mortar bonding laid between them. In SMAS, the components are stacked without mortar bonding and therefore, the accurate and uniform size of component is required than that in conventional one. The distance between adjacent components(3 mm in the test) can be wider for easier stacking work by the robot.

(2)The difference in accuracy level between masonry works and robot works should be adjusted. The accuracy of components depend on their production cost. However, it is not a only way to produce very accurate and uniform components but a robot-oriented construction system with redundancy to allow size errors is desired to be developed.

(3)The characteristic reinforcement system is almost satisfactory but is slightly difficult for robot work. The mechanical joint with screwing should be improved.

(4)The ready-made computer programs such as a palletizing and a depalletizing program which had been developed for manufacturing in the factories were employed in the test. They could be examined and improved for the building construction use.

The system developed in this project, features the advantages of (1)leading itself to fabrication in diverse designs since compact structural members are handled, (2)convenient application to rebuilding and retrofitting urban regions since it can work efficiently in areas of limited space, and 3)utilization as an integrated building production system since it can be readily linked with CAD/CAM systems.

Acknowledgment

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