DEVELOPMENT OF A NEW STEEL ERECTION SYSTEM
- WASCOR RESEARCH PROJECT REPORT (PART 3) -

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ABSTRACT

This paper introduces a new erection system of steel beams and columns by applying robots for building construction. This system is composed of crane, positioning, adjusting, welding, climbing scaffold robot and so forth.

Features of this system are shown by the following items.

a) Robots for positioning, adjusting and welding operations are mounted on a platform.
b) The platform of the climbing scaffold robot moves vertical and horizontal directions for syncronizing erection process.
c) By applying the above mentioned method, scaffolds are removed from the erection work.
d) Positioning and adjusting of the heavy structural members are done by automatic cooperative motion of the crane, positioning robot and adjusting robot.
e) The erction operation is almost automated by applying this system.

On the process of this robotized erection system design, we developed the following technological supporting systems.

a) A three dimentional computer graphic simulation system for studying dynamic behavior of the robotized erection system.
b) A small scale model simulator for the cooperative motion feasibility study of the crane robot and climbing scaffold robot.

1. Introduction

As for a steel frame construction system, procedures for robotization were examined. Specifications and detailed designs of construction robots were prepared and then the system itself was evaluated. The goal of the system is to meet the following requirements:

① It is an acceptable system to a site, because the design and construction are not changed extendedly from the conventional method of concreting in site.
② Simplified connection of steel frames and large simplification of construction permit easy robotization.
③ Robotization of steel frame construction can eliminate the need for temporary construction such as scaffold and reduce costs for temporary construction.
④ Robotization can also eliminate the need for working at high places to increase safety and largely reduce accidents.
⑤ It permits reduction in workers at site and easy personnel

management.

2. Construction System Scope

Possibility of construction by robots and applicability were mainly considered in basic designing of robots used in this system.

Fig.2 shows a concept of steel work in a construction site robotized by this system and Table 2 shows types and numbers of costruction robots.

3. Construction Method

3.1 Material and Connecting Method

As shown in Fig.2, a pre-assembling method of steel frames is used and column members are temporally connected by fitting them in the direction of gravity.

Beam members are also temporally connected by fitting them in the direction of gravity and a pin method is invented (see Fig.3). Columns, girders and beams are pre-assembled at a factory.

3.2 Procedure of Steel Work

In this system, steel work is devided into 15 sections as shown in Fig.4 and steel frame construction is separately carried out in each section.

The assembling flow chart of the block "a", the most typical one among those indicated in the plotting drawing (Figure 4) of steel framework, is given in Fig.5. Fig.4 shows movement of climbing scaffold robots mainly.

Fig.6 shows basic movement of climbing scaffold robots in steel frame construction. Self-climbing scaffold robots move to a specified place, assemble and install members of framework.

3.3 Time Schedule of Steel Work

Table 2 shows a work time schedule of a typical section(4 columns and 4 beams) in this system. If working time is eight hours a day, steel frame construction of a model site (7 floors x 15 sections) with this system requires about 42 days including days for carrying in and carrying out robots (see Table 3).

3.4 Control System of This Robot System

Control system in this system is shown in Fig.7. Each robot is controlled from a central control room. In the central control room, there is a host computer, which is connected to a local CPU of each robot through a distributor on a transfer car.

4. Robots

The configuration of the steel construction robotization system is shown in Fig.8. Each robot is detailed hereunder.

4.1 Climbing Scaffold Robot

4.1.1 Function

The climbing scaffold robot, when mounting the 2F girders, rides on the transfer car. From that point, it performs the task of assembling the girders and columns while climbing by itself.

The assembly is done by the coordination of the climbing scaffold robot, adjusting robot, welding robot, and crane robot. The beams are attached beginning with the highest level and proceeding downward.

Moreover, in order that the climbing scaffold robot can be transported by truck, the floor is constructed so that it can be compacted.

4.1.2 Structure

Up and down movement is performed by means of a hydraulic cylinder built on the boom.

The adjusting robot, positioning robot, and welding robot floor are constructed, move, and work on the surface of the upper floor so rails and a rack to run on are attached. Then, at each of the central and corner turntables where the robots perform their tasks, because of the times when the load of the members rests on the adjusting robot, a clamping device is installed on the base of the robot.

On the surface of the upper floor (long side), a gripper for girder is attached for allowing the ascent and descent of the climbing scaffold robot.

Moreover, on each side, a sensing unit is installed.

4.1.3 Transfer Car

The transfer car is operated manually and is moved to the designated location carrying the climbing scaffold robot. The transfer car faces parallel with the long side of the climbing scaffold robot and carries the climbing scaffold robot's short side.

4.2 Adjusting Robot

4.2.1 Function

The girder that has been automatically hoisted is lowered onto a turntable by the operation of the crane robot.

The posture of the girder on the table is gauged by two ultrasonic sensors attached to the rear section of the table and by rotation of the table, the posture of the girder is aligned for installation. In the case of a column, because of its heavy weight, the tables rides on top of the lower column and the upper column rests on that while it is being lowered. Next the posture is gauged in the same way by the ultrasonic sensor and the sensing unit mentioned above. The table is rotated bringing the posture of the column into alignment for insertion.

4.2.2 Structure

The adjusting robot has a common base with the positioning robot, extending an arm horizontally past the vertical pivoting axis. The turntable is constructed of such a size so that it will arrive at the positon where the member is attached.

As in the illustration, this is a cantilever but since in the case of a girder the table supports the entire weight, it is necessary that it be constructed of dimensions able to withstand this load.

The size of the turntable was determined by the positioning accuracy of the crane when it lowers the column and by the condition that the pins of the column joint ride on top of the table. In order that it will be able to absorb the shock when girders or columns are lowered onto it, cushioning material such as hard rubber is used for the surface of the table.

The rotation of the table is driven by means a reducer and a timing belt. Once the girder or the column is clamped by the positioning robot, the turntable has an ascent-descent as well as a rotating mechanism that allows it to be lowered and withdrawn.

4.3 Positioning Robot

4.3.1 Function

The girder or column received on top of the adjusting robot is clamped to the hand of the positioning robot and conveyed to the point of installation determined by the sensing unit. At this time, the suspension wires for each member are left attached and the weight of each member is borne by the crane robot. The crane robot is left shut off while being moved.

Thus the positioning robot applies only horizontal pressure to the clamped member, and maintaining that posture, conveys it to its destination.

4.3.2 Structure

As mentioned above, in order to enable movement, the robot has six degrees of freedom including horizontal, vertical, a pivoting axis, and three axes in the wrist.

Moreover, when members are raised and lowered, it is necessary this movement be coordinated with the movement of the wires on the crane robot, but in order to allow for a slight delay, the wrist section is equipped with a cushion mechanism consisting of a vertical spring.

The vertical axis is fixed and interferes with the girders when they are conveyed by the crane robot to the turntable. Thus, the vertical axis itself runs along the bearing on the base and is built to be raised and lowered by a rack and pinion. On the upper part of the climbing scaffold robot a groove is cut, and the vertical axis is lowered into that groove.

Moreover, as stated above, the base of the positioning robot is joined to the adjusting robot. When a girder is placed on top of the adjusting robot, that weight and moment act ultimately on that base. At the position on top of the floor of the climbing scaffold robot where the positioning robot handles the girder, a clamping device is attached as in the diagram. The adjusting robot and the positioning robot are installed on rails on top of the climbing scaffold robot and are run by means of a rack and pinion.

In this manner, the adjusting robot and positioning robot project out from the floor of the climbing scaffold robot when the columns for the corner sections are assembled and the work is performed.

4.4 Welding Robot

4.4.1 Function

After the girders have been installed, both ends are welded by one welding robot each. The positioning of the welding torch is performed by wire touch sensing.

The columns are welded by a single welding robot. The positioning of the welding torch is performed by industrial television of the sensing unit and also by wire touch sensing.

4.4.2 Structure

Taking into account in particular the welding of columns, the welding robot is made as a horizontally multijointed robot with five degrees of freedom.

5. Evaluation of The New System

In the study of a robotization system, whether or not the exsisting technology can cope with the system should be discussed, making preliminary evaluation by models which embodies the tasks of the proposed design. If this is feasible, it means that simply the proposals worth evaluating and reviewing from technical point of view can be selected.

As the technique for reviewing, WASCOR used the simulation by computer graphics and a miniature simulator. In the computer graphics simulation, the propriety of the robot operation system was validated by simulating overall dynamism of the system. Also, we developed the miniature simulator to review the inter-robot cooperative works, a technological essense of the proposed system, in order to validate its technological feasibility. We need to add such general judgements for the technical evaluation when evaluating the proposed robotization system.

It becomes important to establish the optimum proposal by identifying the issues in the prposed system through reviews as mentioned in the above, and then feedbacking the insufficiencies found to the proposal of next stage. Photos 1, 2 show three dimension CG output. The simulator is summarized in Fig. 9.

6. Conclusion

The assemblying of steel structure is simple itself, which allows the independent operation of the task in the process of the whole procedures. Thus in this study, firstly the total system was designed with consideration on the framework members suitable to the robotization. Then, the total body was discussed in detail to make the image of required robots, and their concept designs were created. Finally the robotized construction system was structured, which robotizes all the tasks besides ground operations, and reduces the number of workers required to 3 from 6.

This system was validated through the miniature models on the cooperative works between a crane robot and a positioning robot, as well as the dynamic reviews by the three-dimensional computer graphics.

Although there are still many more outstanding issues remaining in this system, its feasibility is deemed to be validated by the methods indicated in the above.

References

(1) Hasegawa Y., "Technologies to be Developed for Successful Introduction of Robots into Building Construction Industry", 5th I.S.R.C., 1988

(2) Tamura Y., Hasegawa Y., Miura N., Tamaki K., "Six Years Experience of Developing Robotized Building Construction System", 6th I.S.A.R.C., 1989

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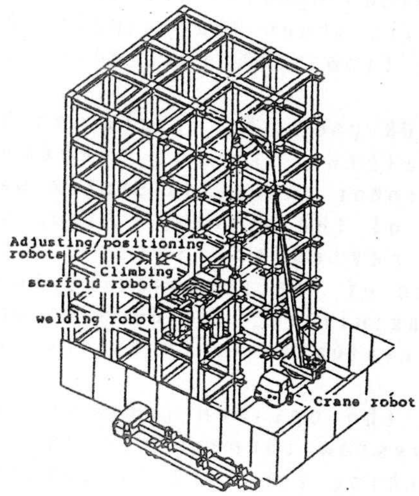

Fig. 1 : Steel Frame Construction

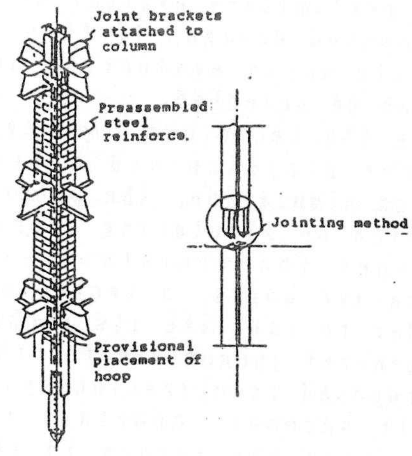

Fig. 2 : Form of Column Members and Jointing Method

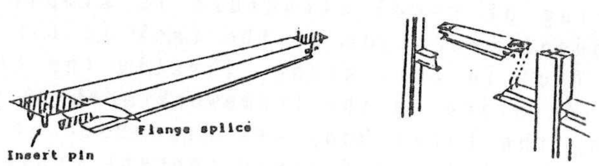

Fig. 3 : Form of Beam Members and Jointing Method

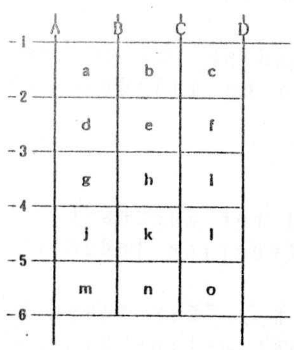

Fig. 4 : Plotting of Steel Structures

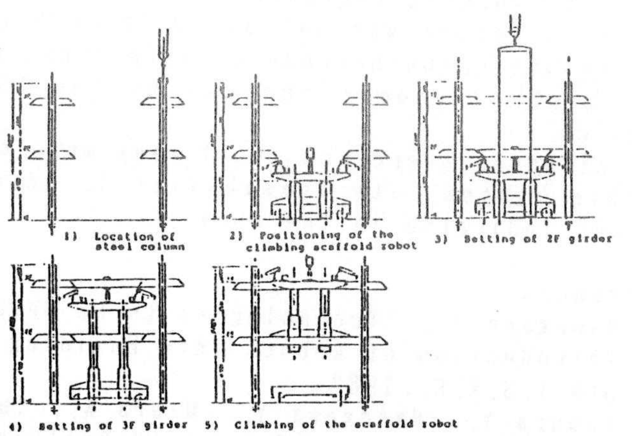

Fig. 6 : Order for Assembling the Steel Structure

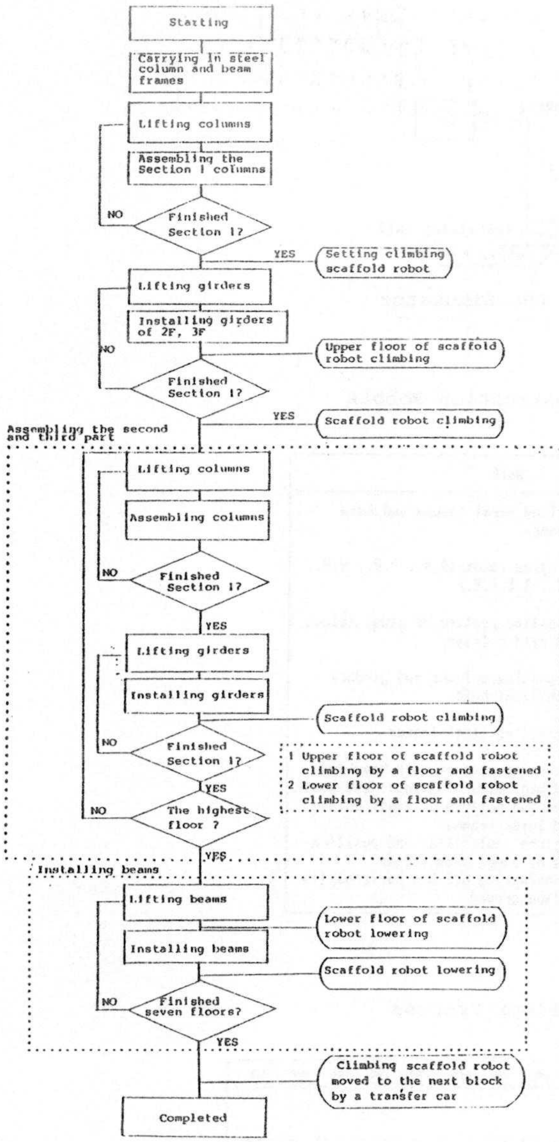

Fig. 5 : Steel Frame Construction Flow Chart

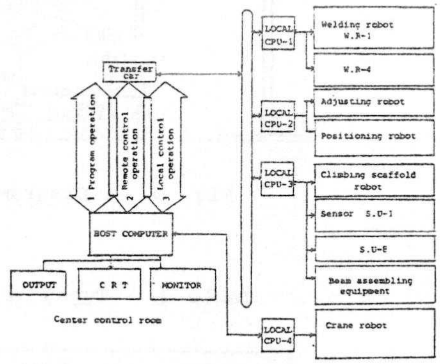

Fig. 7 : Control System

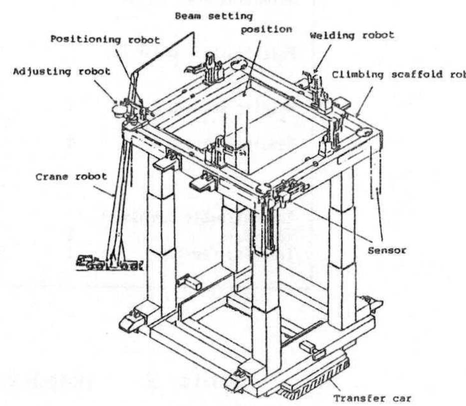

Fig. 8 : Configuration of the Robotization for the Steel Structure Construction

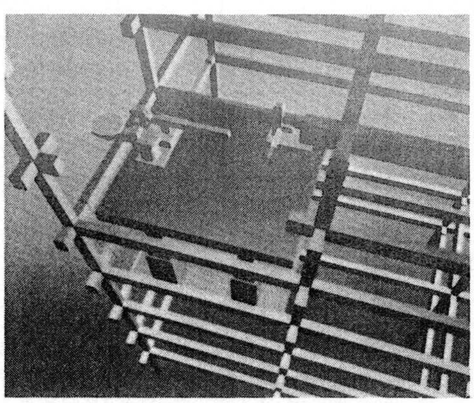

Photo 1 Climbing of the Climbing Scaffold Robot

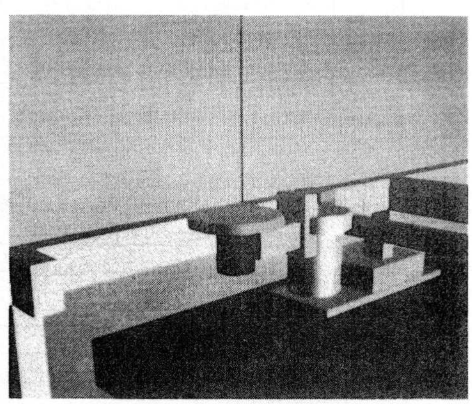

Photo 2 Positioning Robot Setting a Girder

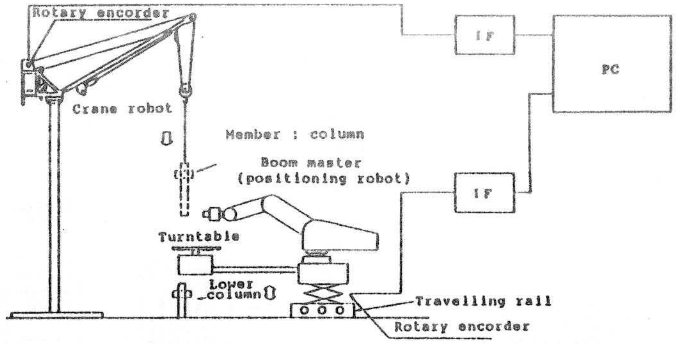

Fig. 9 : Diagram of the Simulator

Table 1 Types of Construction Robots

Name	Number	Work
Crane Robot(C.R.)	1	Lifting steel column and beam frames
Climbing Scaffold Robot(C.S.R.)	1	Carrying robots(A.R., P.R., W.R., S.U., & B.A.E.)
Adjusting Robot(A.R.)	1	Adjusting posture of steel column and girder frames
Positioning Robot(P.R.)	1	Supporting columns and girders with tight hold
Welding Robot(W.R.)	4	Connecting steel frames
Sensing Robot(S.R.)	8	Measuring pins of both beam ends and pin holes of joints, and position and posture of steel column and joint frames
Beam Assembly Equipment (B.A.E.)	1	Posture controlling and positioning of steel beam frames
Transfer Car(T.C.)	1	Transferring C.S.R.s horizontally on the ground

Table 2 Standard Block Process

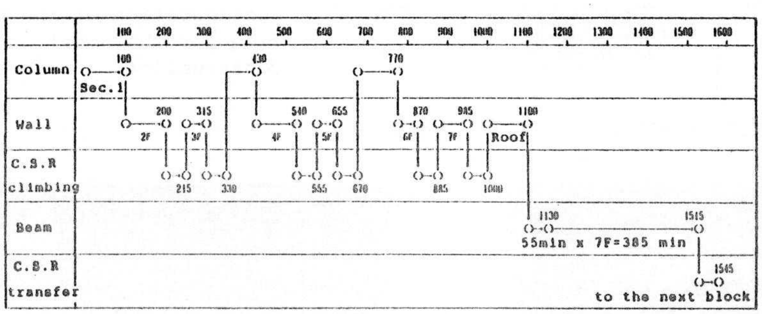

Table 3 Steel Structure Erection Process (8h./day)