Improvement of a Computer Integrated and Automated Construction System for High-rise Building and its Application for RC (Rail City) Yokohama Building

Junichiro Maeda(*), Yasuyoshi Miyatake(**)

(*)Deputy General Manager, mechatronic Technology Department,
Machinery Division, Shimizu Corporation,
Seavans South, No.2-3,Shibaura 1-chome, Minatoku, Tokyo, Japan
TEL.03-5441-0107 FAX.03-5441-0886
(**)Adviser, Shimizu Corporation,
Seavans South, No.2-3,Shibaura 1-chome, Minatoku, Tokyo, Japan
TEL.03-5441-1111 FAX.03-3643-7260
E-mail miyatake@fort.shimz.co.jp

Abstract

A variety of improvements have been added to the Shimizu Manufacturing system by Advanced Robotics Technology (SMART) developed by Shimizu Corporation based on evaluation of the results from the system's application in the construction of a building in Nagoya, Japan several years ago. The improved system was used this time in the construction of a building in Yokohama, which was not only larger than the Nagoya building but more complicated in design.

In this paper, I compare the characteristics of the system application plan for the Yokohama project with the one in Nagoya. I describe the improvements, with particular emphasis on automation technology, discuss the procedures used in carrying out the construction, and examine the implementation results. Finally, I touch on directions of future developments.

1. Introduction

The environment surrounding the construction industry in Japan is becoming increasingly severe. The shortage in the absolute number of skilled construction workers, the bearers of the construction industry, and the aging of the work force year after year are issues which are growing serious. In addition, reflecting the long-term depression of the Japanese economy, further reductions in construction costs are being pursued. For these reasons, the industry faces the serious task of coming up with a revolution in the construction production process that will create appealing working environments and release the industry from its labor-intensive nature while improving productivity.

The Shimizu Manufacturing system by Advanced Robotics Technology (SMART) was developed as one proposal for this challenge. Under a comfortable environment free from the effects of rain and wind, the system automatically carries out a variety of construction tasks for high-rise buildings, from assembly of the building frame to finishing work and installation of facilities.

This system was first applied on a substantial scale in 1992 in the construction of a building in Nagoya, Japan. I reported on the results of that project at the 11th ISARC held in Brighten, UK. Based on evaluation of those results, improvements were added to increase the system's level of applicability, and the improved system has now been used in the construction of a building in Yokohama. Photo 1 shows an outside view of the Yokohama project under construction. This building has a total floor area four times larger than the Nagoya project and has 1.5 times as number of stories. The design is also more complicated, employing a set-back design for the higher stories and complicated corners for standard floor shapes. (see Figure 1, Outside view of the RC Yokohama Building)

2. System application plan

2.1 Outline of site

Table 1 shows a comparison of the RC Yokohama

Building with the Nagoya Juroku Bank Building. In Yokohama, the total floor area was approximately 75,000 m^2 and the area of a standard floor was approximately 2,100 m^2. In addition, there are 30 stories above ground and two basement floors. Above ground, steel-frame construction was used, while the underground portion was made with reinforced concrete steel-frame construction. The project was begun in July 1994 and is scheduled for completion in June 1997. The middle of Table 1 shows the layout of a standard floor. Compared with the Nagoya building which was a simple rectangle, the Yokohama building is more complicated, employing stepped corners.

2.2. System arrangement

As shown in Figure 2, the main frame of the system is made up of a temporary steel framework roof called the hat truss and four jacking towers which support it. Vertical and horizontal conveying systems are located on the underside of the hat truss, and a lift-up mechanism for raising the hat truss is incorporated in the bottom of each tower. The bottom of the hat truss is called the operating platform. The top of the hat truss is covered with a highly translucent sheet that serves as a protective covering, while around the outside hangs a protective mesh sheet which covers the entire working area and which is reinforced by a protective framework. The interior working space surrounded by the hat truss and protective covering brings to mind an image of a manufacturing plant and hence is called the "construction plant." Within this plant, the assembly of the building takes place one floor at a time.

Table 1 also shows the amount of equipment installed at the Yokohama project compared with Nagoya. Yokohama had 2.8 times the surface area for a standard floor and involved the transportation of a greater volume of materials, therefore, a total of 2 vertical cranes, 10 trolley hoists for horizontal conveyance, and 24 overhead cranes were installed. The lift-up mechanism used in Nagoya was appropriated for use in Yokohama. To accommodate the increased load, the hydraulic jacks were upgraded to 150 ton models. The arrangement of vertical and horizontal conveying systems is shown in Figure 3. Also, as shown in Figure 2, at the loading floor, a temporary scaffold was built outside of the building and two overhead cranes were used for suspending materials in trolley hoists.

2.3 Outline of system functions

(1) Lift-up

The lift-up mechanism automatically raises the construction plant as a whole unit. While synchronizing the operation of the lift-up mechanism, which consists of four jacking towers supporting the total plant weight of 1,650 tons, the structure climbs the height of one floor, four meters, within two hours.

(2) Automated material transportation

Delivered construction materials are automatically transported non-stop to their installation position on the operating platform. Materials are suspended in a trolley hoist at the loading floor and are transported horizontally to a waiting vertical crane. After being conjoined to the vertical crane, the trolley hoist is carried to the operating platform where an overhead crane meets the load in succession and carries it to its installation point. When the attaching of the construction member at the destination is completed, the empty hoist automatically returns to the loading floor. In this cycle, multiple hoists operate at the same time and continuously supply materials to the operating platform. The multiple hoists are transported through the efficient selection of overhead cranes by the conveyance route mapping system, the heart of the control system. Photo 2 shows a steel-frame member being transported.

(3) Assembling of steel-frame

The steel-frame columns and beams transported by the automated conveying system have self-guiding joints which allow them to be attached without being touched by a human hand. This was based on the same approach used at Nagoya. Removal of the sling was also done automatically. Adjustment of the vertical accuracy of positioned columns was carried out by an automated laser measurement system. While reading the system's digital display, an operator used the adjustment bolts built into the column to adjust its vertical alignment.

(4) Automated welding of steel-frame

For the welding of column joints, we used horizontal multi-layer welding robots. For the implementation of the construction at the Yokohama building, we added the improvements described below.

3. System technological improvements

Almost all of the equipment used in Nagoya was appropriated for use in Yokohama. Based on evaluation of the application results in Nagoya, problem points were carefully examined and various improvements were added. Figure 4 lists the aims of improvements and specific improvements implemented.

3.1. Streamlining assembly and disassembly

A major problem at Nagoya was the large amount of time and labor required for the assembly and disassembly of the hat truss and equipment. Consequently, we made streamlining assembly and disassembly work our number one improvement issue. We used a single truss for a portion of the vertical crane, simplified the transport and assembly of equipment itself, and streamlined the guide rails. We also modified the metal brackets for the traveling rail of the overhead cranes used for horizontal conveyance; they can now be safely adjusted within the hat truss. We also worked to reduce the labor required for the lift-up system's assembly and disassembly. We separated the hydraulic system into two parts and converted the piping to a block system. For the hat truss, we made the entire structure temporary and arranged it so it could be assembled and disassembled in large block units.

3.2. Improving equipment universality

When this system is appropriated again in the future, universality of the equipment will be important. So it could readily be used at any construction site, we made changes such as using monitor displays for the control room control board and using touch panels for the destination indicator operating panel. Photo 3 shows the interior of the control room.

3.3. Improving conveyance efficiency

To further improve the efficiency of the conveying system, we increased the number of computers used for control, decreased the load on central processing equipment, and modified the conveyance control rules to reduce the waiting time for hoists.

3.4. Improving conveyance safety

Another major improvement was our incorporating functions in the control logic to prevent collisions during conveyance of suspended loads with installed members and jacking towers, etc.

3.5. Improving column welding robots

The following two points are the major improvements we made for the application at the Yokohama project.

(1) Increased welding speed

For the middle layer of welds, we increased the current, raising deposition efficiency and reducing arc time.

(2) Improved finishing weld

We modified the lining method for the final layer bead, and improved the appearance of the finishing weld bead. This time, we also carried out welds on thick plates of over 50 mm, verifying the performance for such cases. Photo 4 shows a column welding robot in operation.

4. Construction procedures

Figure 5 shows the flow of the SMART system construction procedures at the Yokohama site.

4.1. Assembly of construction plant

After construction of the basement building frame, the four jacking towers and the lift-up mechanism were set on the basement floor and the hat truss was assembled on the first floor slab. The hat truss was assembled in advance into blocks as large as possible on the ground and then lifted and pieced together using a large crane. Photo 5 shows the hat truss being assembled. After attaching the conveying equipment and other items to the underside of the hat truss, it was raised and connected with the tops of the jacking towers. Together with this, the protective covering was attached and the assembly of the construction plant was completed.

4.2. Repeated construction

Figure 6 shows the repeated construction process (cyclic process) for a standard floor at the Yokohama site. The cyclic process includes assembly of the steel-frame, positioning of floor slabs, attachment of exterior wall panels, positioning of the facilities and machinery unit and the interior partition materials unit. Finally, the lift-up is carried out and the construction of one floor is complete. Floor slabs, which are pre-cast concrete (PC) panels made in a factory, were automatically conveyed and positioned. The exterior wall panels were a combination of PC panels and curtain walls. In both cases, they were brought into the construction site as completed units, with even glass installed at the factory, and were automatically conveyed to their destination and put into position. Photo 6 shows PC floor panels and Photo 7 shows PC exterior wall panels being transported and positioned.

4.3. Disassembly of construction plant

When construction of the final floor was completed, work began on disassembly and removal of the plant. First the protective covering was removed. A folding frame was used for the protective covering and each folding unit had to be suspended and lowered to the ground one unit at a time by trolley hoist. Next, the hat truss was "lifted-down" by removing the bottoms of the lift-up jacking towers one unit at a time. After the hat truss was lowered to a point close to the building roof, the lifting-down was completed and a tower crane for disassembling the remainder was installed on top of the building. The crane was then used to disassemble and remove the hat truss in blocks.

5. Results

As of the end of January, 1997, a portion of the construction plant disassembly work still remained, so a little more time will be necessary to analyze and evaluate the final results of the construction, but I can summarize what we have learned so far.

5.1. Improved work efficiency

The number of days required for the cyclic process was originally 7, but we managed to reduce this to 5.5, as shown in Figure 6. The main reason for this was an increased conveyance efficiency which resulted from a combination of factors including elimination of initial failures in the conveying equipment, transition to highly efficient construction procedures and operating methods, and improved skills on the part of equipment operators and assembly workers. Table 2 shows changes made by floor in transportation and installation time for construction members above floor seven, where the construction of standard floors began. In addition, Table 3 summarizes by floor the number of pieces transported per hour. As a result of these improvements, what began as a 7 day cycle became 6 days by the 12th floor and 5.5 days by the 15th floor.

5.2. Reduction of manhours

We examined the manhours of specialized workers needed to assemble, adjust, and maintain equipment in comparison to the Nagoya project. As the amount of equipment installed at Yokohama was different, we made allowances to compare the two cases under identical situations. We found that approximately 50 percent fewer manhours were required this time. Nagoya was the first time the system had been applied, but we believe this figure is the result of the improvements described above in section 3.

At the moment, we are still in the process of totaling and analyzing general labor manhours for construction involving steel-frames, floors, external walls, facilities, etc. The general labor hours will represent the overall effect of the technologies involved in all weather-protection, automation, and industrialization.

5.3. Improved site environment

Photo 8 shows the interior of the construction plant. The all-weather covering system completely insulated the plant interior from wind and rain, and made it possible to proceed with work regardless of the weather conditions. The construction plant interior was transformed into a bright, spacious and moderately ventilated space which protected workers not only from rain and wind, but also the cold of winter, the heat of summer, and the direct rays of the sun. In addition, the technique of building one floor at a time eliminated the need for high-altitude work, and the protective covering created a safe site free from the dangers of flying objects and falling.

In addition, automation and industrialization have reduced work in poor conditions and labor-intensive work.

6. Conclusion

The final evaluation of construction results at this site will require more analysis and study, but we have obtained the results described in the section above. The architectural design involved in this building was quite complicated, but we have been able to verify that our system is fully applicable to the kind of conditions presented in this case. However, construction projects of such a large scale as this one are not very common, and to better apply our system to a variety of sites with different conditions in the future and make it an attractive system, particularly in economic terms, we look forward to developing numerous variations and their evaluating system before the application.

References

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[2] Maeda, J. (1994). "Development and Application of the SMART System", The 11th International Symposium on Automation and Robotics in Construction, May 1994

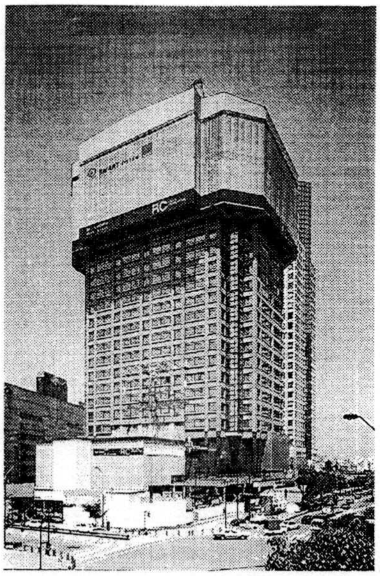


Photo 1. Outside view of the Yokohama project under construction

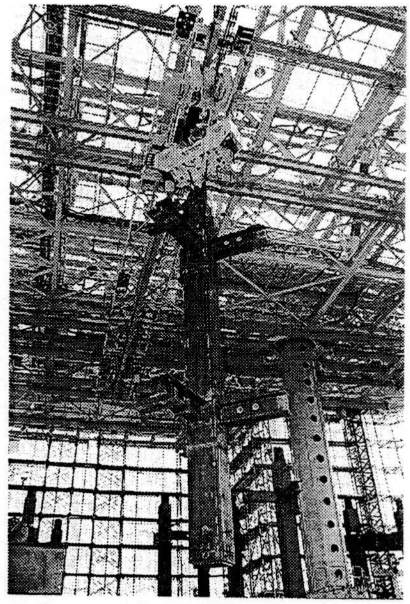


Photo 2. Transpotation of steel column

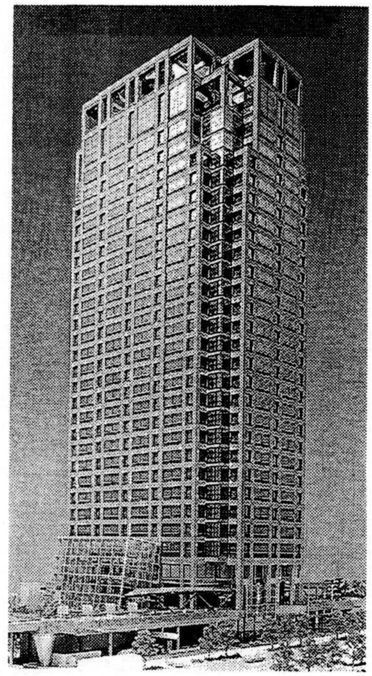


Figure 1. RC Yokohama Building

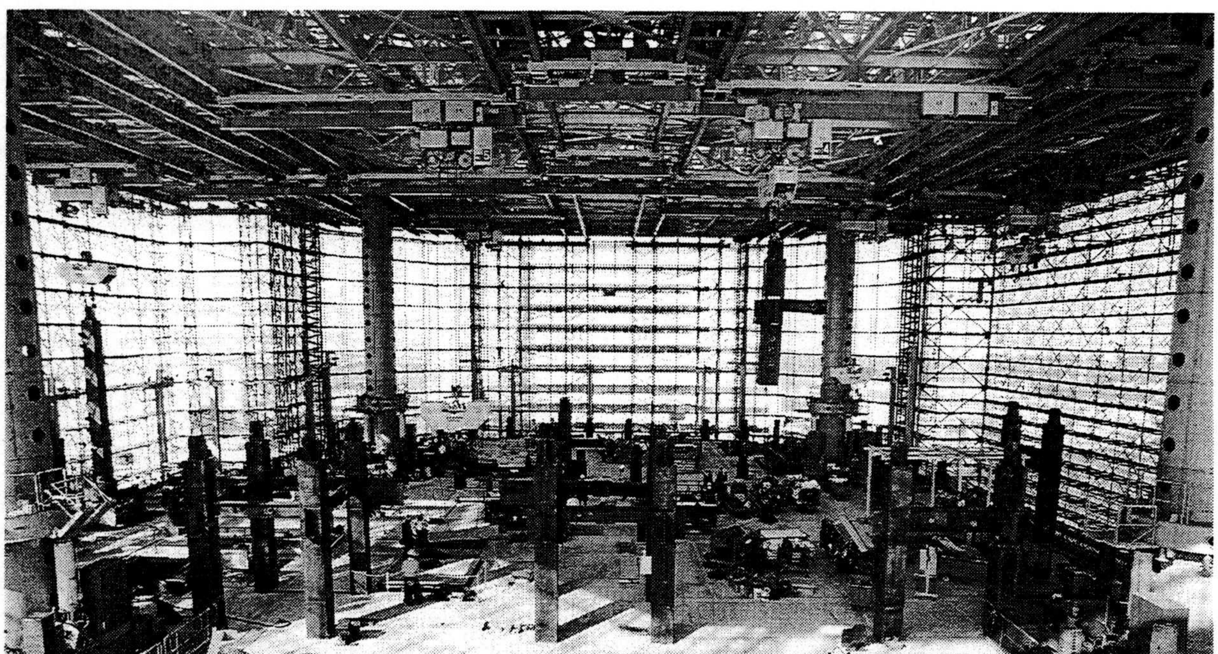
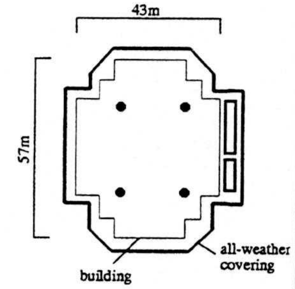
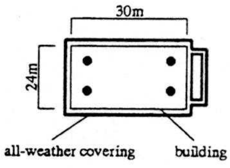


Photo 8. Inside view of the construction plant

Table 1. Comparison of Yokohama project with Nagoya project

	Rail City Yokohama Building	Nagoya Juroku Bank Building
Outline of building:		
Total Floor Area	75,000 m^2	20,000 m^2
Standard Floor Area	2,100 m^2	750 m^2
Building Height	132 m	88 m
Number of Stories (above ground)	30 stories	20 stories
Shape of Standard floor		
Equipments:		
Vertical Crane	2 sets	1 sets
Overhead Crane	24 sets	10 sets
Trolly Hoist	10 sets	5 sets
Jacking Tower	4 sets	4 sets
Hydraulic Jack	150 ton × 12 sets	120 ton × 12 sets

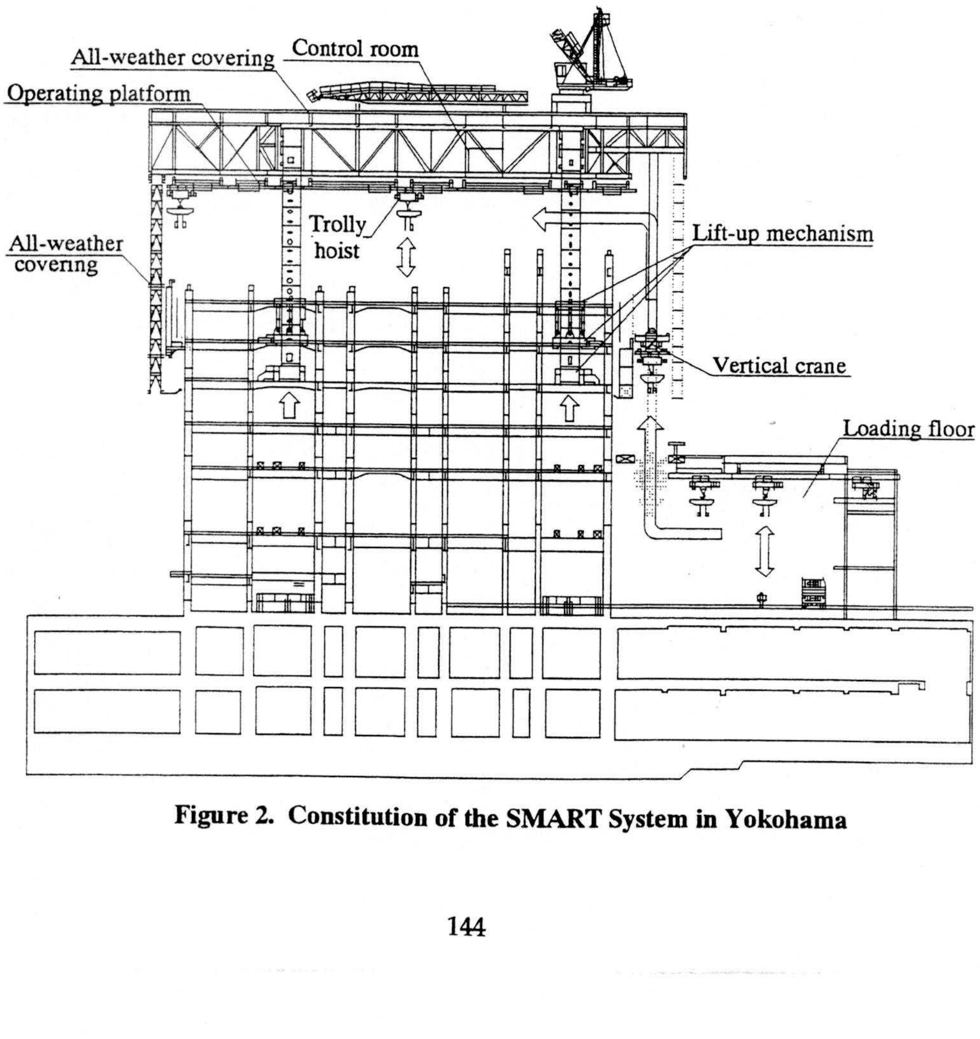


Figure 2. Constitution of the SMART System in Yokohama

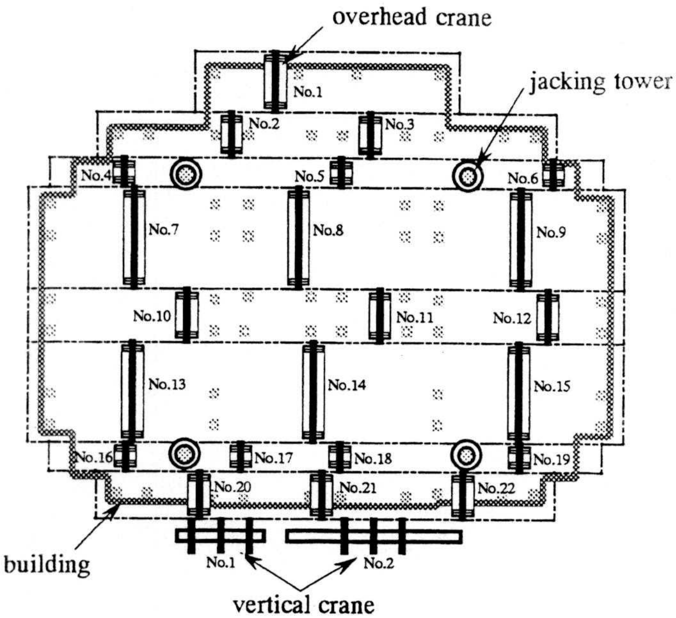


Figure 3. Composition of transportation equipments at the operating platform

Improvement aim	Application area	Items implemented
Streamlining assembly and disassembly	Vertical Conveyance	· Conversion of a portion of the conveyance structure to a single truss · Simplification of guide rails
	Horizontal Conveyance	· Modification of the traveling rail bracket
	Lift-up	· Conversion to blocks for hydraulic piping · Separation of hydraulic system into upper and lower rings
	Hat truss	· Use of temporary steel-frames for entire structure · Assembly and disassembly in block units
Improving universality of equipment	Operation	· Use of large monitor display in control board · Use of touch panel system for destination display
Improving conveyance efficiency	Operation control	· Increased number of control computers · Conveyance time reduction through passage time estimate control
Improving conveyance safety	Operation control	· Elimination of collision of suspended loads with installed members or jacking towers during conveyance

Figure 4. Main technological improvements

Photo 3. Control room

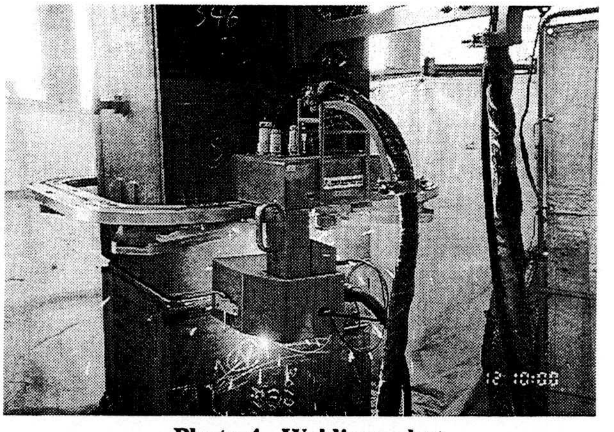


Photo 4. Welding robot

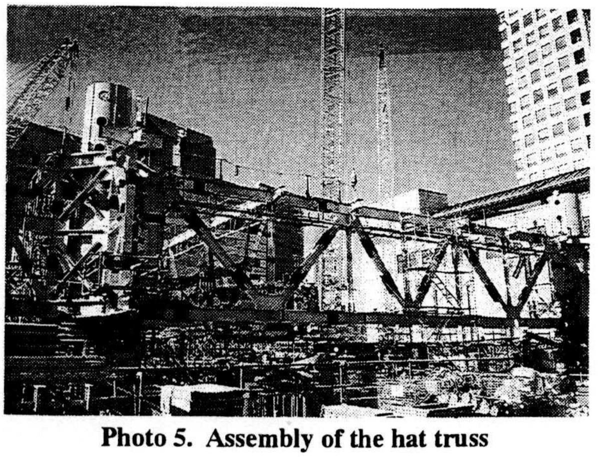


Photo 5. Assembly of the hat truss

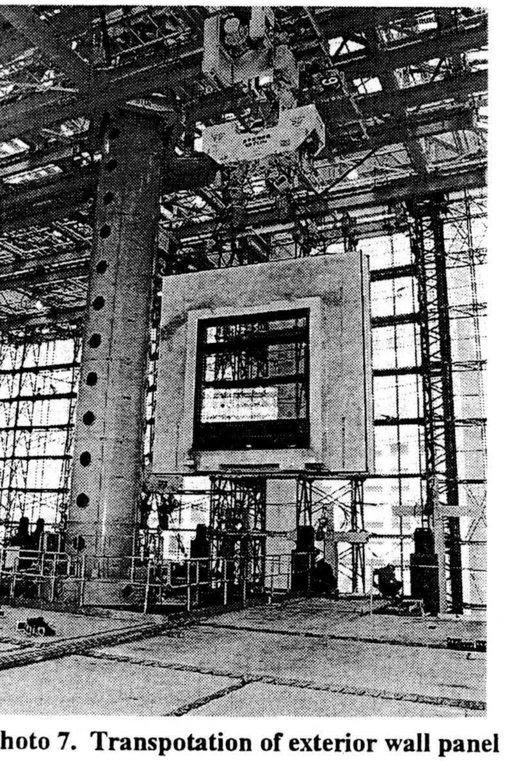


Photo 7. Transpotation of exterior wall panel

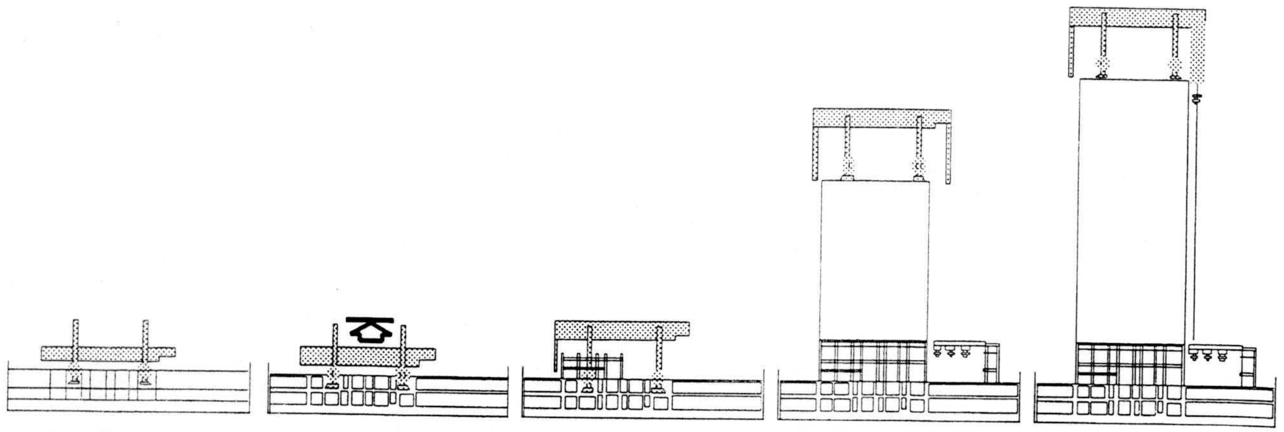


Figure 5. Constuction procedure

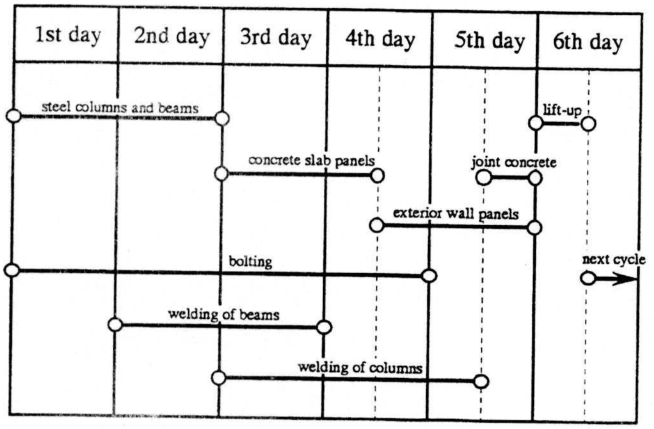


Figure 6. Cyclic process (5.5 days)

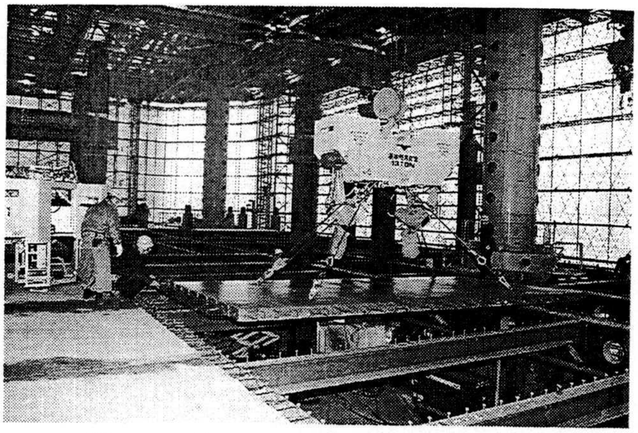


Photo 6. Transportation of floor slab panel

Table 2. Improvement of transportation and installation time of members

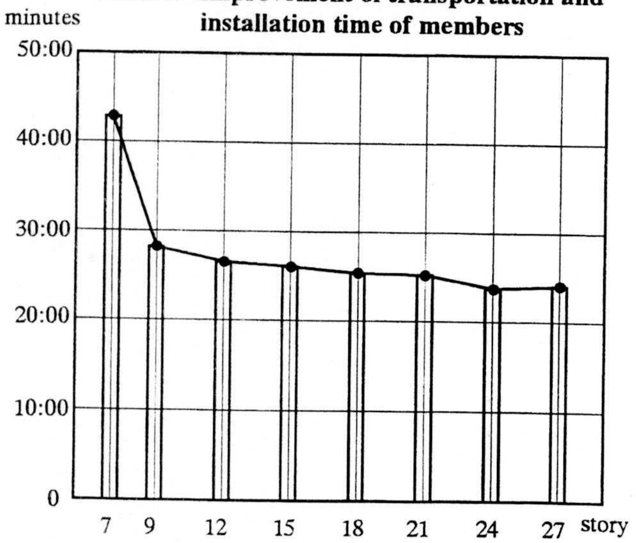


Table 3. Improvement of number of transportation