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DEVELOPMENT OF AUTOMATIC EXTERIOR PRECAST CONCRETE WALL PANEL CONSTRUCTION SYSTEM

Hideo Tanijiri; New Production System Development Department,
Building Construction Division, Fujita Corporation
Kohei Sato ; Building Construction Department,
Osaka Regional Office, Fujita Corporation
4-6-15 Sendagaya, Shibuya-ku, Tokyo, 151, Japan

ABSTRACT

This automatic exterior precast concrete wall panel installation system performs a series of in-situ construction work, from spraying paint on exterior precast concrete wall panels, to transporting and installing them. The system consists of an automatic exterior precast concrete wall panel paint spraying system, an automatic transportation system and an automatic installation system, and, during work is underway, is intensively controlled through a control station located in a field office in order to ensure the system's uninterrupted operation, safety, line balance, as well as the registration of work completed or in progress, and the issue of commands.

This paper first introduces, as a development example, how the system in question was applied to the construction of the exterior walls of a 13-storied building located at a minimal possible lot in a populated urban area, a project which triggered off the system development. Then the evolution of the system development, the method of system design, the characteristics of the system, the summary of the equipment incorporated, and the results of the system's application to the abovementioned building project will be described.

1. INTRODUCTION

At present in Japan, the construction industry is in the midst of addressing the development of various types of automatic construction systems. However, building production involves a diverse and extensive area, therefore putting an automatic construction system to practical use requires partial, phased and continual functions, and due to this, a partial, practical development type project is required to enable system commercialization.

In developing the proposed automatic construction system, priority was put on establishing the objective of the development, as well as its scope and position. In close liaison with speciality suppliers and contractors, and through the collection of a wide range of information in order to narrow essential points down, we were able to apply the system to an actual construction project, with success.

This paper reports on the techniques and attentive points required in the future for field engineers during operation of the system, through making reference to the evolution, outline, and effect of the system's development, as well as the problems that ensued.

2. EVOLUTION OF THE SYSTEM'S DEVELOPMENT

2.1 General Description of a Building on which the System was Applied

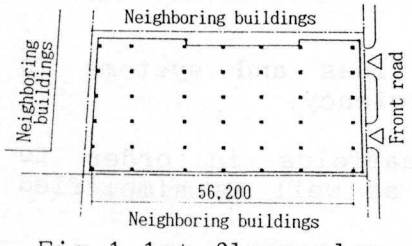

Fig.1.1st floor plan

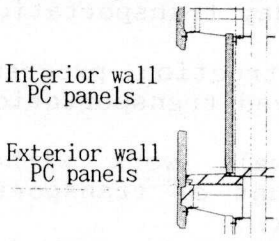

Fig.2.Section of exterior wall

Scale : Stories - 2 basements, 13 ground floors, and 2 penthouses
Site area - 1,823m²
Building area - 1,654m²
Total floor area - 21,142m²
Building height - GL-10.1m～GL+54.3m
Construction: Basement - reinforced concrete
Ground floors - steel
Use : Hotel
Construction period : 15 months

2.2 Problems Involved in Construction

Because of the structural effects of industries these days, constructors suffer from an increasing demand for building construction as well as from shorter construction periods, the resulting shortage of labor which urges for more industrialized construction, and the primary control of the materials and labor force by material and/or physical suppliers during the stage in which constructors program phase-to-phase construction schedules, have become factors which complicate the control of production at construction fields even more.

By the same token, we at Fujita Corporation have also been facing such problems as: ① building owners' requirements becoming more and more diversified, requiring too many elements to be changed midway through the design and/or construction phase, and therefore taking an unexpectedly longer time to complete, ② owners requiring that their buildings be completed in as short a period as possible, (in this case too, completion periods are ruled by suppliers despite the use of the industrialized framing method), and ③ many building construction projects having to be executed in confined, narrow sites in urban areas.

2.3 Extracting Essential Construction Conditions and Establishing Themes

With a view to the problems mentioned in the preceding section, the classification of the requirements limiting the execution of construction would allow the following specifications:① the construction of both underground and ground floors must be proceeded simultaneously by using a method in which after the first floor of building has been completed, construction must proceed to the second floor and to the first basement simultaneously, ② in planar planning, only one tower crane is allowed to be erected, ③ because there is only one access road available in most cases, it is necessary to enable the simultaneous use of the building's first floor with a frontage of five spans, once completed, as a space which allows for concrete placing, underground excavation, the hoisting of structural materials down to the underground floors, and the handling of steel members for ground floors, and ④ exterior wall PC panels can be paint-sprayed.

To summarise the abovementioned essentials, re-programming the construction schedule, and the timely allocation of effective transportation procedures will be prerequisite. As a result of classifying the elements entailed with the jobs mentioned above, we also eatablished parameters to overcome the following problems:

a. Construction execution conditions

① Providing transportation facilities as required in order to simultaneously complete the structural works of both the underground and ground floors.

② Quantifying the amount of work, and the amount of materials and equipment to be transported, thereby eliminating variations in the amount of day-by-day transportation.

③ Formulating the construction program as lines and systems in order to ensure improved transportation efficiency.

④ Executing exterior wall work without scaffolds in order to ensure a reduced amount of transportation as well as simplified ground structural work.

⑤ Removing jib cranes and clamshells at the earliest possible time in order that no portions of work are left incomplete for later finishing.

⑥ Providing stationary transportion tracks in order for small spaces to be utilized safely and effectively.

⑦ Making provisions so that the work of spraying paint against exterior wall panel surfaces can be executed under rainy or windy weather.

⑧ Making provisions so that the labor force can be reduced, and that uniform quality can be ensured for the exterior wall panel surfaces receiving finishes to produce a paint sprayed surface with a granite-like texture finished with a jet burner applied in five passes.

⑨ Reducing management labor in order to ensure a reduced, management burden of staff members.

b. Establishing a theme

In establishing a theme with which unmanned construction can be addressed, focus was placed on the systematization and automation of the work of construction exterior PC panel walls, which conventionally greatly affect the types of work subjected to the established parameters mentioned above, as well as on construction programming, therefore interfering with the control of management.

2.4 Analysis of Problems Involved in the Established Theme

Table 1 shows the results of the analysis made on the existing problems listed by work category and procedure.

a. Problems involved in the installation of PC panels

① Each PC panel is heavy, weighing three to five tons, and therefore requires a tower crane. However, there is a chronic shortage of crane operators.

② PC panels must be installed on exterior walls located at high places, therefore their installation work tends to become dangerous.

③ One series of work requires a PC panel to be hoisted, hauled temporarily fixed, adjusted for accuracy, and permanently fixed in place, thus requiring four or five skilled technicians.

b. Problems involved in the work of spraying paint against a PC panel surface

① The work of spraying paint onto exterior wall panel surfaces must be performed on scaffolds located at high places, hence there is a possibility that accidents will occur.

② Work is affected by weather, and therefore involves work management risks.

③ All exterior scaffolds must be entirely protected behind canvas in order to prevent paint which is being sprayed from

scattering towards neighboring buildings. This protective canvas aggravates the environment in which workers are doing the spraying.

④ Much of the finished quality depends on the interest and experience of paint sprayers, and confirming the finished quality of the entire area from the scaffold is extremely difficult.

⑤ Currently, PC panels tend to be finished in advance, including their coating, at plants. However, under the present-day circumstances in which increasing quantities of PC panels are demanded as well as the fact that PC panel production is becoming more and more industrialized, cast-in-place concrete wall construction remains predominant due to the problems that plant spaces encounter in allowing the production of PC panels, their transportation efficiency, and their potential risk of damage during transit.

Table 1. Construction procedures currently practised, and analysis results of the problems

Operation flow	Description	Labor difficulties				Problems conceivable from the production control point of view		
		Dangerous	Hard	Dirty	Monotonous	Complex	Unsteady	Discontinuous
0. Deliver PCa panels from the plant ↓	The PCa panels are produced at the plant, and delivered to the jobsite by truck.							
1. Unload PCa panels ↓	The PCa panels are unloaded from the trucks, and transfered to the storage yard.	○					○	○
2. Store and inspect ↓	The PCa panels are inspected, and stored on the 1st floor of the building under construction.							
3. Hoist and haul ↓	Each PCa panel is hauled by a crane to the place where it is to be installed.	○				○	○	
4. Temporarily support ↓	The PCa panel is then set upright with its bottom set on the nearest floor point, and its top is temporarily supported from the pent roof.	○	○			○	○	○
5. Pull in and temporarily fix	With a wire rope hitched to the top of the PCa panel, the panel is pulled into its designated bay, and then bolted loosely.	○	○			○	○	○
6. Align and inspect	Then, the panel is accurately positioned and securely bolted.	○	○			○	○	
7. Permanently fix	The fasteners of the panel are permanently welded and a rust inhibitive paint is applied to the welded surfaces.				○			
8. Seal the joints	From the exterior scaffold, the joints adjacent to the neighboring panels are sealed.				○			
9. Tape the sealed joint surfaces	The joints are distributed accurately, marked, and the joint surfaces are taped.				○			
10. Spray paint	A sealer is sprayed on the overall joint surfaces, three coats of paint are applied to produce a granite-like texture, the tapes are removed, and finally a top coat is sprayed on.	○		○	○		○	○

2.5 The Basic Idea and Construction Conditions for the System

Table 2 shows the basic idea of the system as being consistent with the construction conditions previously established in 2.3.a.

Table 2. System's basic idea and construction conditions

Basic idea for hardware \ Construction conditions (the numbers come from those in 2.3.a)	①	②	③	④	⑤	⑥	⑦	⑧	⑨
○ Use a belt conveyor for both the excavation of the basements, and the removal of the excavated material.	○		○		○	○			
◎ Use an overhead traveling crane for the vertical haulage of materials from the basements and the handling of materials aboveground.	○		○		○	○			
○ Use a multi-sectional construction method for the construction of superstructures and for the execution of finishing work.		○	○						
◎ Use a traveling hoist for the vertical and horizontal transfer of exterior PCa wall panels.	○		○		○	○			
◎ Provide a material transfer device at the nodal points of each construction process in order to make the transportation process continuous.			○			○			
◎ On the first floor, perform automatic paint spraying, but do not include manned paint spraying work at construction site.		○	○	○			○	○	
◎ Provide an image television set at key points on the construction site, as well as a communication system, in order to facilitate remote, centralized control.			○						

Note: A ◎ mark means the hardware directly relating to the installation of exterior wall PC panels to be performed using the proposed systems.

3. SYSTEM OVERVIEW

Through the reorganization of production items and the construction environment, measures were taken to simplify, mechanize, and automate the production procedures. A series of operations involving the transportation, installation and finishing of exterior PC wall panels, was also integrated as well as systematized.

Carrier system operation and the control of its safety, balanced line control, production progress control, and the control of commands and records, were all intensively performed through a control station located in the plant office. However, hitching ropes to, and unfastening the ropes from, PC panels, adjusting the accuracy of their installation, and securing them permanently, were all performed by hands by PC workers,due mainly to the reasons that development time and costs were limited, as well as because it was necessary that someone remain to confirm whether the PC panels had been accurately installed. The diagram below illustrates the flow by which the proposed system performs a series of PC panel production and installation operations.

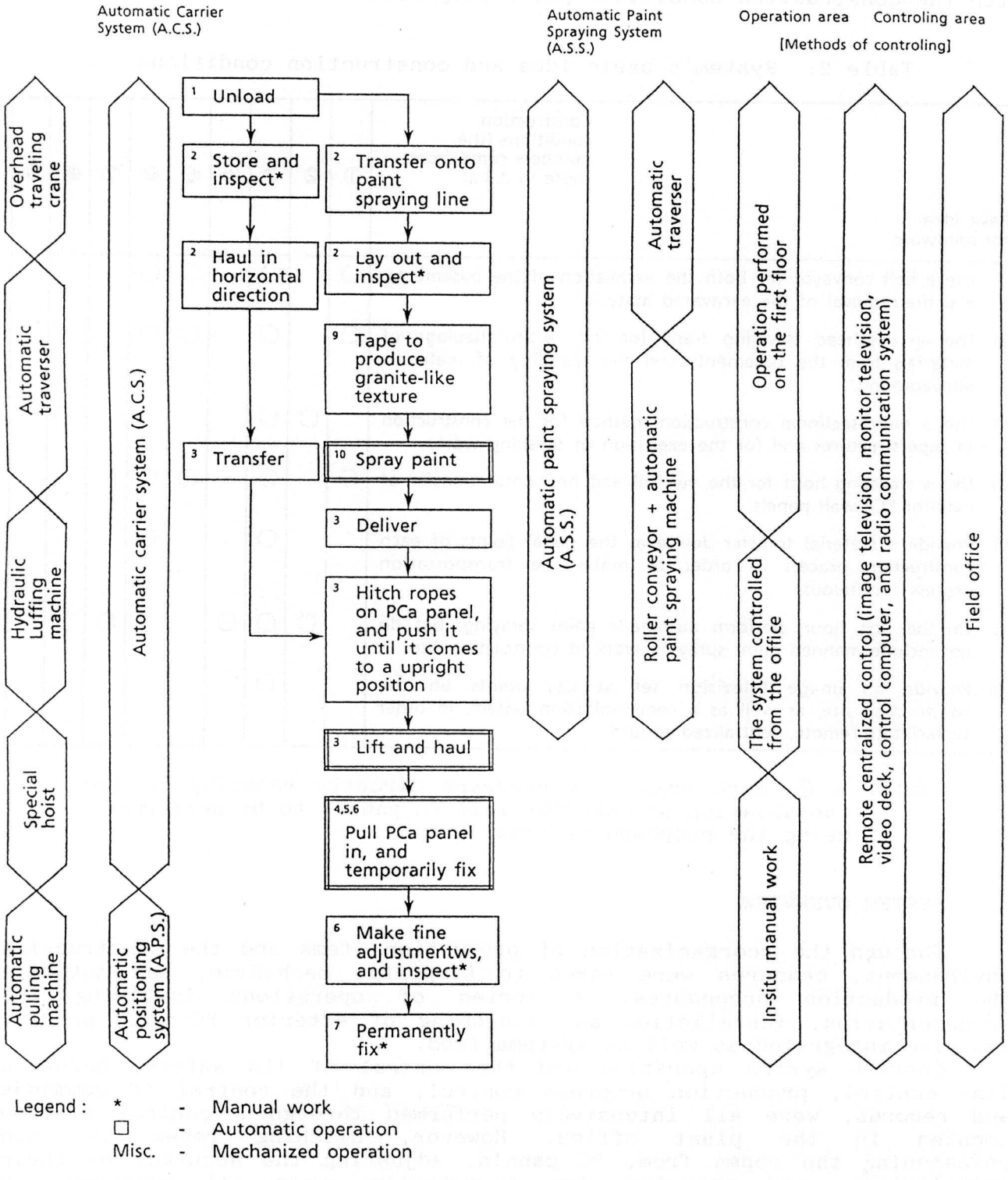

Fig.3. System diagram

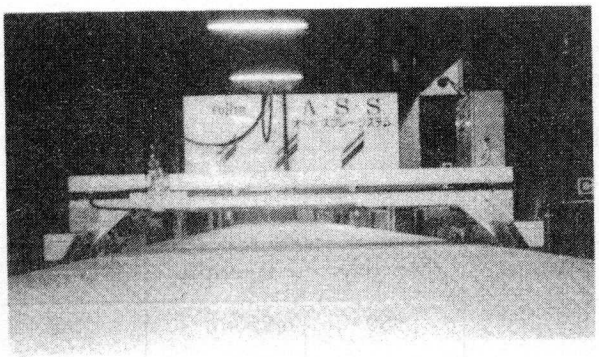

Photo 1. Automatic paint spraying system (A.S.S.)

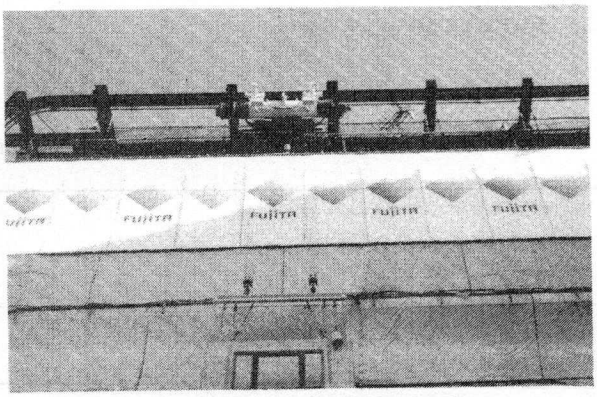

Photo 2. Automatic carrier system (A.C.S.)

Photo 3. Automatic positioning system (A.P.S.)

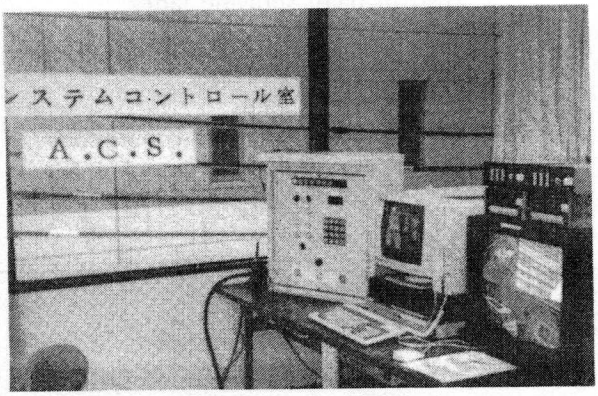

Photo 4. Integrated control system

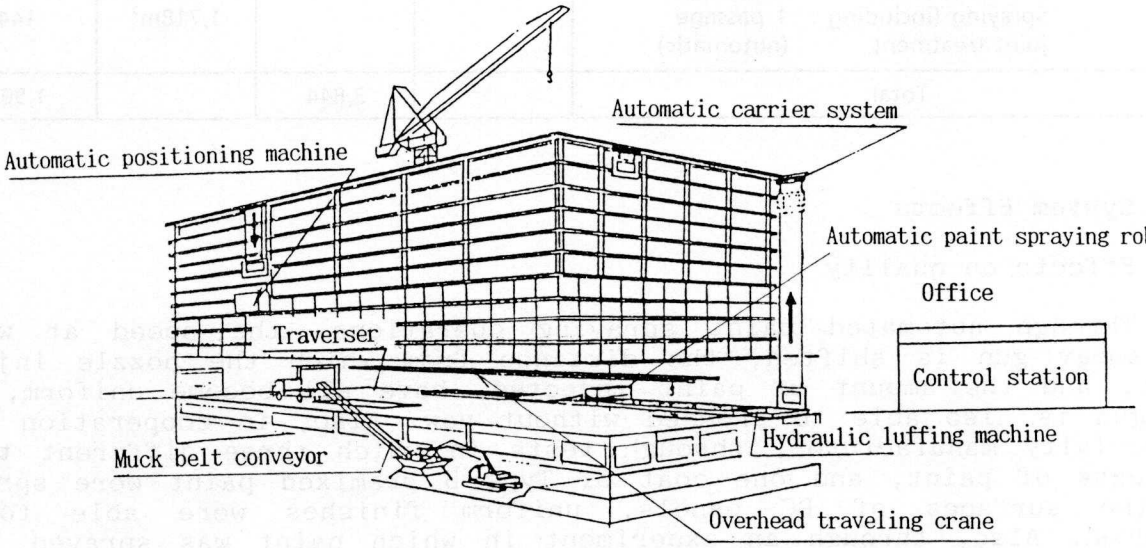

Fig.4. System's coceptual illustration

4. RESULTS OF SYSTEM APPLICATION

4.1 Resultant Data

Table 3 shows the data achieved through an application of the system.

Table 3. Resultant data.

		Conventional method		Proposed system	
		Quantity	Man days	Quantity	Man days
Temporary works	Exterior scaffold and protection. Gondola and protection	6,950m²	950	6,950m²	53
General temporary works	Tower including an operator	11 mos.	253	10 mos.	207
	Overhead traveling crane	10 mos.	20	10 mos.	20
	A.S.S.			1 unit	
	Material, installation and removal costs of paint spraying lanes			As reg'd	51
	A.C.S.: Special hoist with an operator			1 mo.	26
	Control device			1 set	18
	Hoist rails			1 set	13
	Hydrualic luffing machine			1 unit	4
	Control computer			1 set	4
	Traverser			2 units	4
	A.P.S.			1 set	45
Installing PCa panels	Material cost	959m²		900m²	
	Installation cost: Conventional method	780P	550	379P	238
	Proposed system			401P	78
Spraying paint	Spraying (including joint treatment): 3 passages (manual)	5,010m²	2,071		
	Spraying (including joint treatment): 1 passage (manual)			3,291m²	598
	Spraying (including joint treatment): 1 passage (automatic)			1,718m²	144
Total			3,844		1,503

4.2 System Effects

a. Effects on quality

Through automated paint spraying operations, the speed at which the spray gun is shifted, the distance from which the nozzle injects paint, and the amount of paint injected, have all become uniform, and the gun is also able to proceed without yaw. Also, in cooperation with a specialty manufacturer, through tests in which three different types of coats of paint, and one coat of Type 3 premixed paint were spraved on the surfaces of PC panels, uniform finishes were able to be achieved. Also, through an experiment in which paint was sprayed in a horizontal direction, rather than in the vertical direction practised by the conventional method, improved paint fixing efficiency was achieved, and no applied paint sagged down the panel's surface.

b. Production efficiency

Table 4. Production efficiency data

		Conventional method	Proposed system	
Labor efficiency	Install PCa panels	1.5p'cs/man-day	5.14p'cs/man-day	Installation efficiency: 342%
	Spray paint on PCa panels:			
	3 sprayed coats of Type 3 paint (manual)	2.42m²/man-day		
	1 sprayed coat of Type 3 paint (manual)		5.5m²/man-day	Spraying efficiency: 227%
	1 sprayed coat of Type 3 paint (automatic)		11.93m²/man-day	Spraying efficiency: 217%
	Total labor	3,844 man-days	1,503 man-days	Labor-saving efficiency: 61%
	Reduction of PCa panel installation period:			
	Installation	110 days	71 days	Reduction ratio: 35%
	Paint spraying	104 days	75 days	Reduction ratio: 28%

c. Miscellaneous effects and features

The features of the proposed automatic exterior PC wall panel construction system are that it:

① is applicable for a wide range of buildings to be constructed in urban areas, from those at narrow sites, to skyscrapers,

② is effective, particularly when the system is applied to public facilities, hotels, and apartments which have double exterior walls provided with evacuation balconies,

③ enables a steady production of PC panels because the system's operation is not affected by weather, site location or labor shortages, due to the fact that PC panels are produced and installed automatically,

④ enables all operations involving heavy PC panels to be performed at the production lines alone,

⑤ creates an improved working environment because the amount of work at elevated places and work in dusty area can be reduced, and

⑥ reduces the number of man-days for which skilled speciality technicians are required.

5. ATTENTIVE POINTS ENCOUNTERED DURING SYSTEM DEVELOPMENT

Matters which had been unpredictable at an early stage and were thereafter encountered in the course of the development of the proposed system, as well as necessary attentive points, are as listed below:

① The time required to think of new programs, through discussions and prearrangements, increased, therefore staff members had to deal with a consistently demanding schedule.

② As this system had never before been applied to an actual project, it was difficult to reflect the labor saved onto contractual unit prices.

③ Establishing initial costs was difficult, particularly for assessing the costs of control related hardware and software.

④ During the stage in which initial planning began, it was necessary to discuss the required license, qualification, and safety facilities with the jurisdictive Lavor Standards Inspection Office.

⑤ Determining a method for processing tax transactions for the associated machinery and equipment of the system as fixed assets, was necessary.

⑥ During the development of automated and/or or unmanned sections of the system, the following items required attention:

a) Because excessive emphasis was placed on the automation and unmanning of the system, its practicability (safety, quality, processes, and costs) tended to be treated as a secondary concern.
b) As a consequence of excessive emphasis being placed on its practicability, the system tended to be developed for the limited application of the one actual building project to which it was experimentally applied.
c) As a consequence of the excessive pursuit of extensive applicability for the system, at one stage of development an inconveniently operable system resulted.
d) Because of unreasonable efforts which were exerted towards the system's development with a very narrow view, excessive time and expense were required to automate such types of work and operations that would have to be eliminated in the future.

6. CONCLUSION

These days, with demand for construction continuing, the Japanese construction industry uses construction procedures based on materials and labor primarily controlled by suppliers, therefore further complicating field production control.

Research and development of the proposed automatic exterior PC panel wall construction system has proceeded in order to find ways to eliminate the difficulties workers traditionally encounter in the haulage of exterior wall PC panels to their installation places, as well as in the production process involving the haulage, installation, and finishing of PC panels at construction sites. Although no one can deny the importance of reducing the need for labor by using industrialized methods, we have put priority on ways of liberating field workers from painstaking jobs, as well as ways of eliminating various risks which might ensue from production control depending on weather, location and working conditions. Therefore, it would be important to materialize mechanized and/or automated consruction as a solution to the aforementioned problems, and based on that philosophy, and with this system viewed as only one of the constituent elements required for further automated construction, we will continue to make further efforts so that areas in which this system may be applied will be further expanded.