DEVELOPMENT OF AUTOMATED EXTERIOR CURTAIN WALL INSTALLATION SYSTEM

Isao Seo [*1] Hidetoshi Oda [*2]
Nobuhiro Tasaki [*3] Hideo Tanijiri [*4]

*1 Technical Consultancy Department
Tokyo Regional Office, FUJITA CORPORATION
WDI Bldg. 3-13-18, Sendagaya, Shibuya-ku, Tokyo 151
*2 Technical Consultancy Department,
Osaka Regional Office, FUJITA CORPORATION
*3 Construction Promotion Department,
Hiroshima Regional Office, FUJITA CORPORATION
*4 New Production Development Department,
Architectural Division, FUJITA CORPORATION

ABSTRACT

The development of automated construction has been promoted in the construction industry in recent years, and this paper based on the project entitled "Automated Construction of Exterior Finish Panel", which was awarded the top prize in the Practical Application Section at the 10th International Construction Robot Symposium, furthers that development. Our corporation has promoted the wide use of this system by refining it through its continuous use. This development pertains to the automated installation technology of exterior curtain wall work. This assembly work of one floor of exterior curtain wall was performed under the same working conditions as those in a plant. It was done by automatically lifting the curtain wall accurately using a simple mechanical device and by constructing in sequence from the upper floor to the lower floor.This paper reports the details of the development, summary of the system, the construction plan, the results and the expansion planned in the future. This report is based on the records of experience of practically applying the system to the installation of exterior curtain walls.

1. INTRODUCTION

In the construction industry in Japan in recent years, there have been various ways in which automated construction has been attempted. Unmanned construction and manpower saving in the construction industry has been promoted by using technology which greatly expands so-called conventional construction methods. Coping with such trends, our corporation has attempted to deal with the automated installation system of exterior curtain walls, which tends to involve various dangerous operations and is influenced by weather conditions. At this point in time, we would like to elaborate on the details of refining and further developing the system by its continuous implementation that was reported on at the 10th International Construction Robot Symposium.

2. PARTICULARS OF DEVELOPMENT

The opportunity for the development of this system came when we examined the possibility of the automation of the installation of exterior curtain walls, which is influenced greatly by the weather and involves dangerous operations. It accounts for a high ratio of the building operation. For the first time, this system was adopted for a mechanically elevated car parking building. As the details of this project were explained at the aforementioned symposium, we decided not to touch upon them here. However, to summarize the system, it is one in which the exterior curtain wall panels are installed successively from the uppermost floor to lower floors while exterior curtain wall panels are conveyed on a stage using 4 units of chain blocks that are installed at 4 corners of structural steel. In response to the favorable results of this application, we have decided to venture into the development of an automated exterior curtain wall installation system and by applying the system to the buildings, which are relatively large in area have a simple configuration, this system was gradually expanded.

3. IMPLEMENTATION OF THE SYSTEM IN THE EXTERIOR ALUMINUM CURTAIN WALL WORK OF MEDIUM AND HIGH-RISE BUILDING

Based on the results of the implementation of the system to the exterior curtain wall panels of a mechanical elevated car parking building, initially, it was decided that the system be applied to the exterior aluminum curtain wall work of a general medium and high-rise building. Description of the subject building, particulars of implementation, summary of the system, construction method and results of construction are described below.

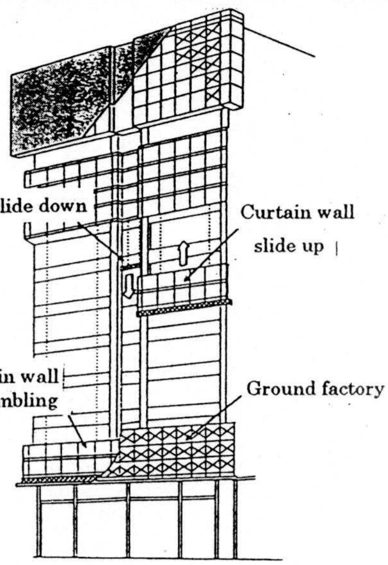

Fig. 1. System summary drawing.

3.1 Summary of the work (A Bldg.)

Construction : S 13 storeys aboveground
Maximum height : G.L.+62m
Site area : 1,367m2
Building area : 818m2
Total floor area : 12,375m2

3.2 Particulars of the implementation of the system

Results obtained by the execution of the automated exterior curtain wall installation system were attempted to be expanded to the exterior aluminum curtain wall work with objectives of improving accuracy of construction and safety, manpower and labor saving in construction, compared with conventional operations.

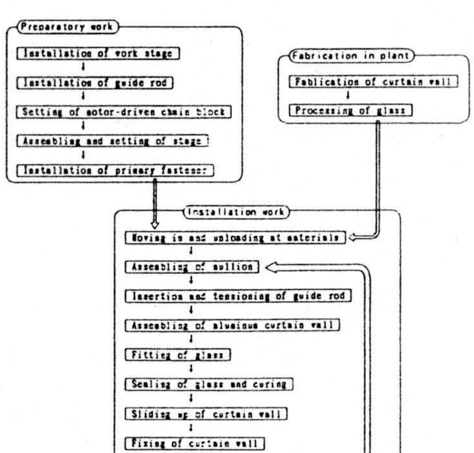

Fig. 2. Flowchart.

3.3 Summary of the system

The system used is the refined and upgraded automated exterior curtain wall installation system that installs curtain wall panels according to the flowchart as shown in Fig.2. The management system of construction situation used was approximately the same as the vertical accuracy management system. It was managed by means of a wire type height detection sensor that was used on the exterior panel.

3.4 Main plans and items for development during implementation

The following is a description regarding the development of the work stage plan, guide rod method and guide roller method, all of which required the most contrivance from the viewpoint of the construction plan

(1) Development of the guide block method

To slide up the aluminum curtain wall assembled in a folding screen manner safely, while maintaining accuracy and to connect the upper and lower panels smoothly, the guide block method was developed. This is the method in which a rod is inserted through the vertical hole in back of the mullion and a part of the sliding stage. After fixing it by applying tension to both ends of the rod, it is used as a guide when sliding up the aluminum curtain wall. Fig. 3 shows the details of the rod.

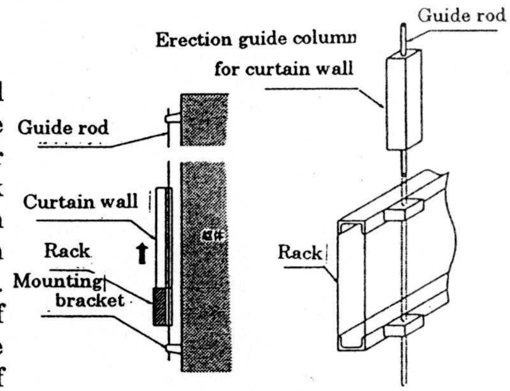

Fig. 3. Guide rod method.

(2) Development of guide roller method

This method was developed so that guide rollers are installed in two steps on both ends of the sliding stage in order to prevent rotation due to the eccentric load and to prevent deflection when moving the curtain wall. The summary of which is shown in Fig. 4.

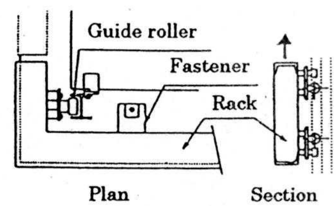

Fig. 4. Guide roller method.

3.5 Results of the application

In this work, the automated exterior curtain wall installation system was applied to a curtain wall portion of approximately 900m2 from 3F to 9F with 24m in width and 15 ~ 50m in height (about 35m in lifting height). The width of the unit to be slid up was divided into 3 for architectural reasons. 10 pairs of glass with the weight of 200kg a pair were incorporated into one unit.

The implementation of this system made it possible to perform the work functionally and efficiently as if the work were being performed in the plant, though it was on the work stage of raised floor type system. Therefore, upgrading of assembling accuracy, safety, productivity, conveyance efficiency, etc., was able to be achieved.

4. IMPLEMENTATION OF THE SYSTEM IN A LARGE HIGH-RISE BUILDING EXTERIOR ALUMINUM CURTAIN WALL WORK - NO. 1

On the basis of the results obtained from the implementation in a medium and high-rise building exterior aluminum curtain wall work, we attempted to apply the system to a large high-rise building exterior wall aluminum curtain wall, which requires a higher level of technology. Description of the subject building, particulars of implementation, details of the system and method of construction and results thereof, are described below.

4.1 Summary of the work (B Bldg.)

Construction	: S and SRC 21 storey aboveground		
Maximum height	: G.L.+98m	Site area	: 4,865m2
Building area	: 3,256m2	Total floor area:	40,103m2

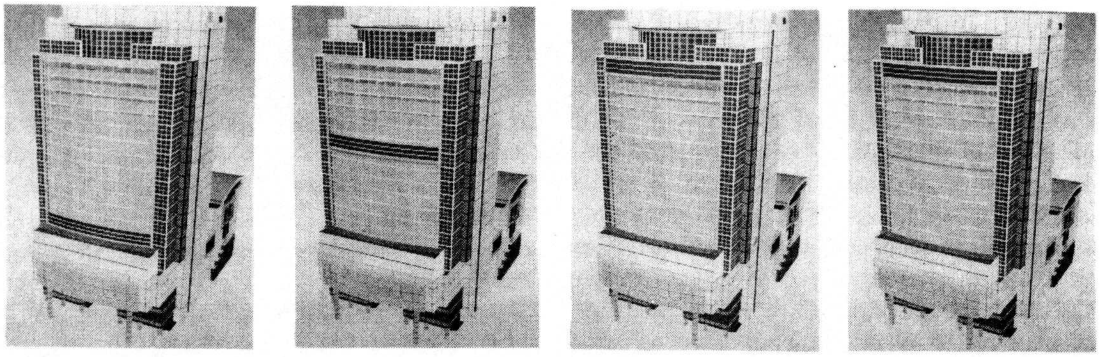

Photo 1. Construction procedure in a large high-rise building.

4.2 Problems involved in implementation

To apply the automated exterior aluminum curtain wall installation system developed through medium and high-rise building exterior work to a large high-rise building exterior wall work, it was necessary to solve the following problems:

① As the building is a high-rise, it was necessary to develop the mechanism so that is more effective against wind load.

② It was necessary to develop an automated measurement system and a control system that can cope with the larger lifting height.

③ In order to increase by a large margin the number of pairs of glass to be incorporated in one unit, it was necessary to structure a new horizontal conveyance system.

4.3 Summary of the system

It is the system in which various devices were made to go with the increase in size and height of the building to the automated exterior curtain wall installation system as mentioned in Chapter 3. The exterior aluminum curtain wall is lifted up automatically from the upper floor to the lower floor and is installed using the construction procedure as shown in Photo1. The basic flowchart is the same as shown in Fig. 2.

4.4 Main items for development in implementation

Newly developed long span rack, combined guide roller and guide rod method, fully automated measurement and control system and chain conveyor system which were developed at the time of the implementation, are described below.

(1) Development of a combined guide roller and guide rod method

It was necessary that the system be able to cope with a wind load, so it had to be secured in order to be implemented in a high-rise building. As the guide rod method, as shown in Fig. 3, had to depend on the connect and disconnect operation that was carried out manually, it was predicted that it would take time and be a dangerous operation at an elevated location where it is exposed to strong wind. Therefore, in this work, the combined guide roller and guide rod method as shown in Fig. 6 which is able to cope with the predicted strong wind, was developed. The main feature of this method is that 8 guide rails are installed on one side and are supported by three points. The rack, transom and mechanism are such that they can cope with the wind load at the elevated location. Also, the guide rail was made in such a way that it can be separated floor by floor.

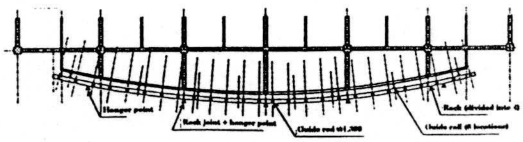

Fig. 5. Plan of long span rack.

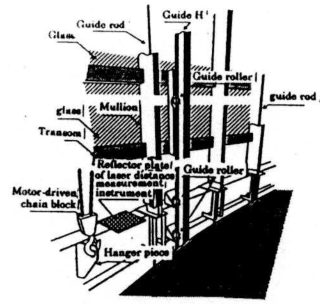

Fig. 6. Combined method of guide roller and guide rod

(2) Development of the fully automated measurement and control system

As the accuracy management system used up to the time of application of the system to the medium and high-rise building, had the possible measurement distance of within 40m (accuracy of sensor), a new contrivance was needed since the required measurement distance reached was as large as 50m in this project. In addition, as the width of the unit becomes 33m, a highly accurate automated measurement and control system was necessary.

In this work, a small laser distance measurement instrument was introduced into the distance measurement sensor and by making motor-driven chain block inverter newly controlled, we were able to realize a highly accurate automated measurement and control system. The sequence to actuate this system is described below and Fig. 7 shows the block diagram of the system.

① By understanding the characteristic features of each motor-driven chain block used in advance and by adjusting them so that they will be driven at the same speed by the inverter control.

② The small laser distance measurement instrument is installed on the uppermost floor, and its reflector plate is installed on the rack.

③ The laser measurement instrument carries out measurement of the distance 5 times a second and transmits the measurement data to the computer in the control room (Photo2).

④ The measurement value of the motor-driven chain block in the center position is held as an absolute value for the management of a measurement value and the inverter actuates when an error of more than ±3mm occurs.

⑤ Under usual circumstances, the slide up is made with the medium speed mode (1.1m/sec) and automatic control is set such that when the error becomes more than 3mm it is switched to the high speed mode (1.3m/sec) or the low speed mode (0.9m/sec) while correcting the error.

⑥ Once the error is corrected to less than ±3mm the chain block returns to the regular condition.

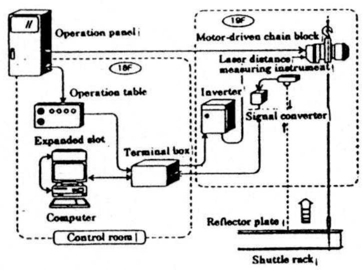

Fig. 7. System block diagram.

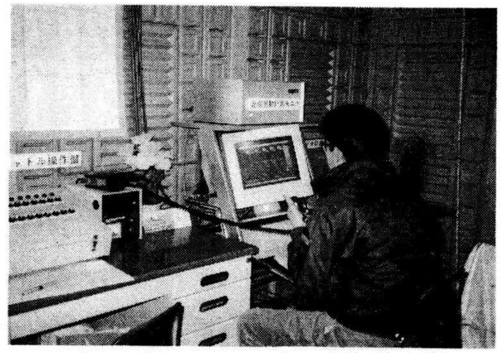

Photo 2. Control room.

4.5 Results of construction

Results of the implementation of the automated exterior aluminum curtain wall installation system in the large high-rise building work are described below.

(1) Construction product accuracy

The quality accuracy control management was performed in the following manner-inspection of the large unit is performed on the assembling rack followed by the conveyance of the large unit by the fully automated measurement and control system within an accuracy of ±3mm. On the floor of installation, the procedure of the final installation similar to the conventional method and inspection were performed. The accuracy standards for passing the inspection was an error of within ±2mm after the assembly and final installation. As a result of conducting a dimension accuracy inspection and the visual inspection of seals, etc., on all units at 26 locations per unit in the presence of the Design Supervisor, there were no parts which failed to pass inspections. Because the work was done at a place where the working environment was similar to that of a plant, we were able to accomplish a high quality construction between each curtain wall and to thoroughly derive quality merits accompanied from making the system larger.

(2) Construction schedule

The required days for one cycle of one unit was 4 days in this case. Considering the fact that the cycle schedule at the time of planning was 8 days using this system and was 10 days using the conventional method, it resulted in shortening of construction period by a large margin. Although in this system, the installation of the curtain wall could not start until after the completion of the erection of structural steel of upper floors, it could be understood from the results that the final schedule would be shortened and there are sufficient merits from the viewpoint of the construction schedule.

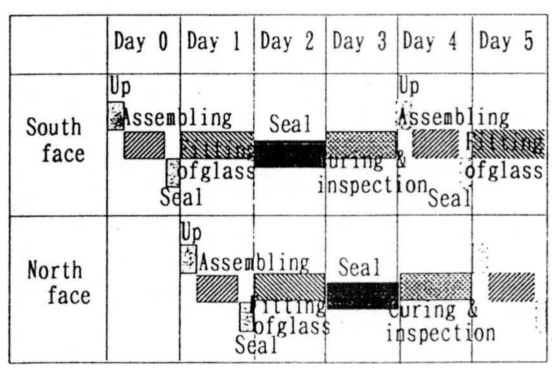

Fig. 8. Cycle schedule

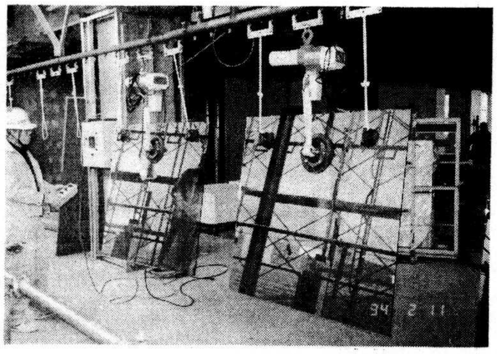

Photo 3. Situation of chain conveyor in operation.

Photo 4. Situation of the automated exterior curtain wall installation system.

5. IMPLEMENTATION OF THE SYSTEM IN THE HIGH-RISE BUILDING EXTERIOR ALUMINUM CURTAIN WALL WORK - NO. 2

Thus far the implementation was limited to the work in Kinki region except the implementation of the system in the automated exterior curtain wall panel of the elevated car parking work in Tokyo. However, this time we were given the opportunity of implementing the system in the installation work of an aluminum curtain wall work in Hiroshima. The summary of subject building, different points and results of construction are described below.

5.1 Summary of the work (C bldg.)

Construction : SRC partly S, 13 storey aboveground
Maximum height : G.L.+61m Site area : 1,653m2
Building area : 1,349m2 Total floor area: 16,350m2

5.2 Main items of improvement in the implementation of the system

(1) Improvement of long span

The rack that lifts up the aluminum curtain wall was adjusted to form a [-letter shape, the motor-driven chain block and guide rails were laid out in the corners for balance and accuracy and safety was secured.

(2) Implementation of the performance verification test of the motor-driven chain block

A gage was attached to the body of the chain block and the measurement of the surface temperature at the time of ascending and descending was conducted confirming that the chain block had the durability to withstand prolonged continuous use .

(3) Resolving the problem regarding the construction of the uppermost floor

By giving consideration to layout of the motor-driven chain block without revising the present design, we were able to apply this system from the uppermost floor though a raking was caused on the floor slab of each floor .

5.3 Results of construction

In this work, the automated installation system was applied to the exterior aluminum curtain wall portion of approximately 2,800m2 in area from 3F to PHF with 10m ~ 61m in height (50m in lifting height). Satisfactory results were also obtained similar to the work implemented before verifying the suitability for wide use of the system.

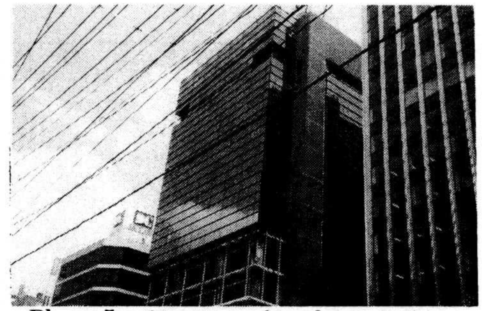

Photo 5. **Situation of implementation.**

6. IMPLEMENTATION IN THE HIGH-RISE BUILDING EXTERIOR WALL ALUMINUM CURTAIN WALL - NO.3

As the last example of the implementation of the system, the work of an office building in Tokyo is introduced here. As the exterior wall was of aluminum curtain wall in this building, the system was applied to all four faces. On the aluminum panel on the western face, a challenge was made to use the layered construction method where the work is executed from lower floor to upper floor in sequence just as it is with the conventional construction method. This allows the construction of the exterior wall without waiting for the raising of the structural steel girder. We were able to demonstrate the excellent features of the system. Summary of the subject building, particulars of implementation, rough procedure of the layered construction method and results of construction are described below.

6.1 Summary of the work (D Bldg.)

Construction: S-partly SRC, RC 18 storey aboveground

Maximum height	: G.L.+81m	Site area	: 13,373m2
Building area	: 1,296m2	Total floor area:	22,056m2

6.2 Particulars of implementation

On the basis of the records of our experience thus far and from the viewpoint of compilation, it was necessary to perform the automated installation of exterior wall on all four faces of the building. As the elevators were in a concentrated location on the western face forming the core of the building, and taking into consideration that the construction schedule would not be met if the construction method had made it necessary to wait for structural steel girders to be raised before work could be started on the exterior wall from the uppermost floor, it became an urgent matter to develop the layered construction method in which the exterior wall is installed matching the progress of the structural steel work from the lower floor. Also, with respect to the other faces, the problem that had affected the finishing work was that the motor-driven chain block was working constantly in the building until the construction of exterior wall had been completed using this system. The problem was resolved by relocating the chain block several times allowing the completion of the remaining work from the upper floors. Thus we were able to proceed with the finishing work without affecting the construction schedule.

6.3 Rough procedure of the layered construction method

① First, assembly of the aluminum panel of one floor was performed on the temporary stage on the second floor and a suspended rack was installed on upper part of the panel (refer to Fig.9).

② Next, using the gondola rail of the exterior wall body that had already been completed as a guide, the aluminum panel of one floor was raised to the floor of construction along the exterior wall, and the installation was made moving them horizontally in two directions, X and Y (refer to Fig. 11) by pulling them to designated position.

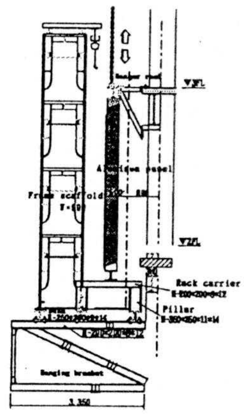

Fig. 9. Section of 2F Ground Factory.

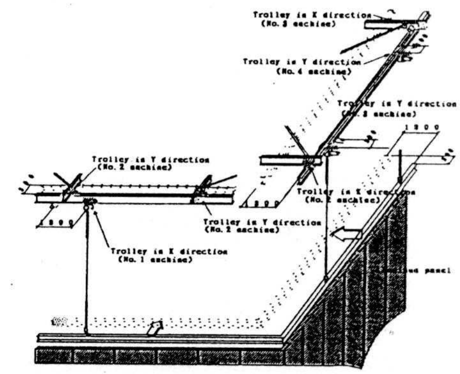

Fig. 10. Lifting up of aluminum panel.

③ As the exterior wall aluminum panel lifted ascends on outside of the completed exterior wall as shown in Fig. 12, it becomes a function to move it in the horizontal direction. Because the panel is in a [-letter shape, it was necessary to move it in two horizontal directions, X and Y. Therefore, the motor-driven chain block and traveling rail themselves were made movable. This system was the one newly developed as a horizontal crane, which combines 1 girder and 2 hoist cranes (2 units of 5t chain blocks). It also was provided with the function of synchronizing each trolley when moving in the horizontal direction .

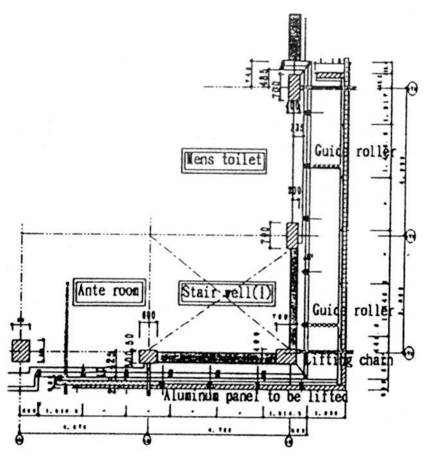

Fig. 11. Plan of northwest face when lifting.

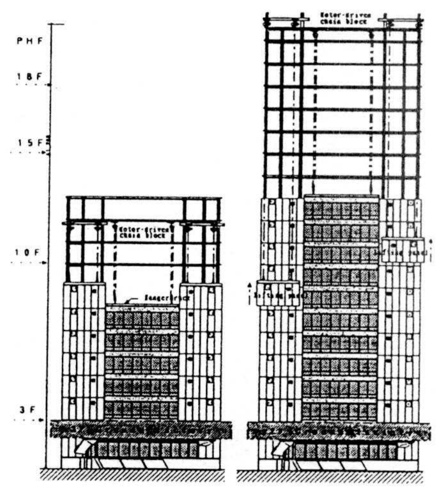

Fig. 12. Situation of installation of aluminum panel on western face.

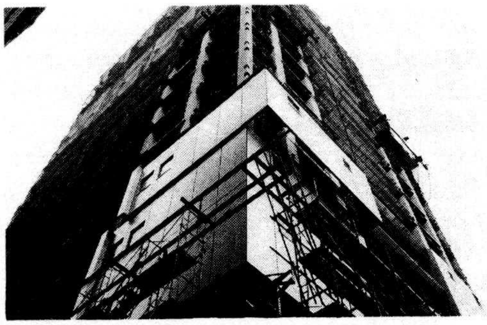

Photo 6. Situation of shuttle up.

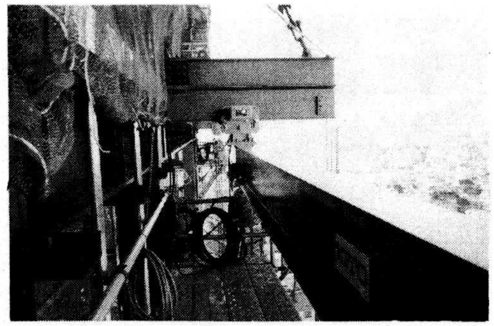

Photo 7. Crane.

6.4 Results of construction

In this work, the automated installation system was applied to the exterior wall portion of approximately 8,420m2 in area from 3F to PHF with 11m ~ 81m in height (about 70m in lifting height), which amounts to nearly 3 times the area compared with previous experiences. The construction schedule progressed at the rate of 4 days/cycle and as there happened to be 4 faces of exterior wall, the work flowed smoothly achieving labor saving objectives by a large margin. A comparison table was prepared for examples of automated construction made thus far, which is shown in Table 1.

Table 1. Comparison table of percentages in the buildingsof application.

	A building	B building	C building	D building	
				Aluminum curtain wall	Aluminum panel
Area (m2)	900	3,000	2,800	5,950	2,470
Extension (m)	24	33	33	83	35
Maximum height (m)	G.L.+50	+90	+61	+81	+81
Lifting height (m)	Approx.35	Approx.55	Approx.50	Approx.70	Approx.70
Pairs of glass (per unit)	10	75	40	78 Eastern face	11 (aluminum panel)
Weight of glass (kg/pair)	200	30	200	40 Eastern face	350 (aluminum panel)
Weight of the unit (ton)	6.5	9.0	13.5	8.0	4.0
No.of chain block (unit)	2	5	6	4	3
Lifting capacity of chain block) (ton)	1.6 (2.8t capacity)	2.5 (5t capacity)	3.5 (5t capacity)	3.3 (5t capacity)	2.3 (5t capacity)
Control system	Automated control system	Inverter control system (±3mm)	Inverter control system (±3mm)	Inverter control system (±3mm)	Inverter control system (±3mm)
Cycle schedule (day)	7	4	4	2~3	4

7. CONCLUSIONS

The development started from the automated exterior panel installation system which was applied to the elevated car park building work was gradually expanded in its scale from a medium high-rise building to a large high-rise building and while that was taking place, it was evolved multi-laterally and continuously. The work progressed in such a manner that for the initial objectives for development, such as upgrading of construction efficiency and safety and quality of construction accuracy, considerable results were obtained. these results were steadily improved on in each project it was applied to. The motor-driven chain block that has become the key technology of this development was a vertical conveyance machine with relatively high serviceability in proportion to the cost and a high synchronizing capacity was added with combination of measurement instrument and control device through refinement.

In the future, we will endeavor to apply the system to various exterior aluminum curtain wall installation works and hope to help make the construction industry more active while aiming at mechanization and manpower savings.

Bibliography

·Masaaki Iwamoto et al.: "A System of Vertically Sliding and Installing Exterior Curtain Wall of a Building ", 10th ISARC,June 1993