Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

A System of Vertically Sliding and Installing Exterior Curtain Walls of a Building

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Abstract

This system, referred to as a "shuttle system," has been developed to enable the vertical sliding and subsequent installation of panels on the exterior walls of a building, starting from its uppermost story, while repeating a series of such operations as (1) sliding a carrier stage down to the ground, (2) on the stage, assembling panels into a panel unit of a size which entirely covers one story height, (3) sliding the panel unit, together with the carrier stage, up to the installation level, and (4) fixing the panel unit in place. Various sensors are provided to enable the panel unit to be installed accurately both in horizontal and vertical directions. The computer located in the field office is interlaced with these sensors. This paper provides a report of the case in which this system was successfully applied to the cladding of exterior walls of two mechanized parking towers.

1. INTRODUCTION

In Japan the construction industry has currently devoted itself entirely to technical innovation. At general contractors, special departments have been established to take on the challenge of the development of unmanned or mechanized construction systems.

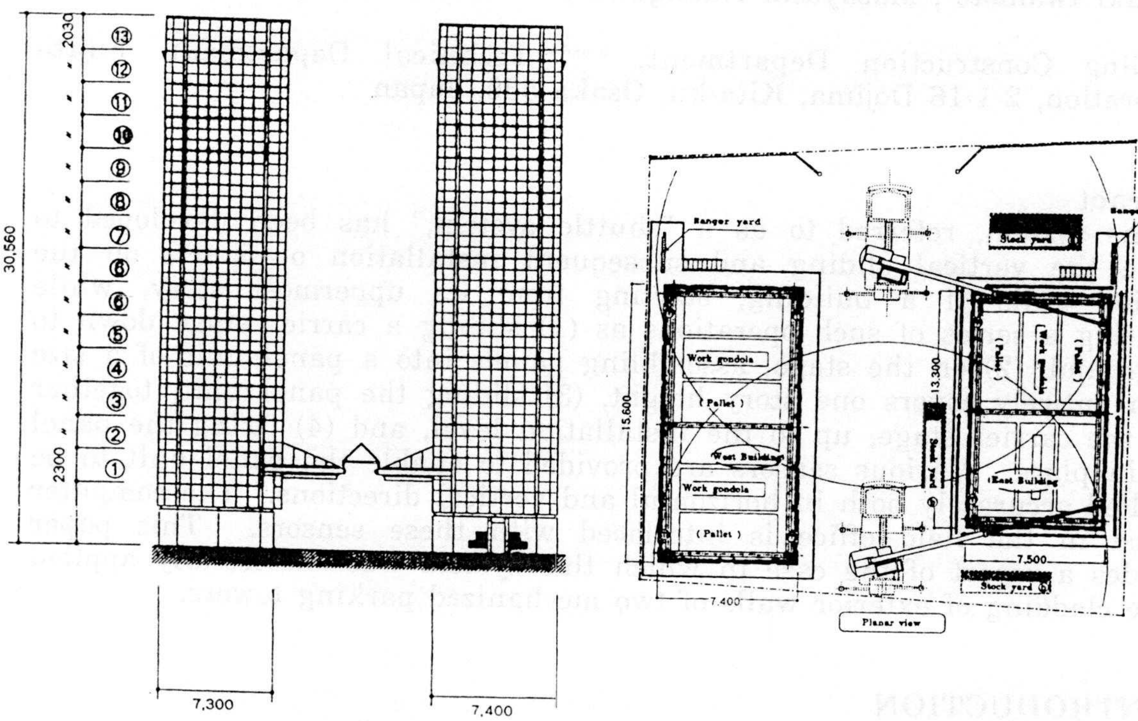
As a step toward the industrialization of fully-automatic construction systems, the Fujita Corporation is the first to develop a "shuttle system." This is a system enabling the installation of panels to clad the exterior walls of a building, without the use of either a large crane or scaffolds. The development focussed on the aim of installing and automatically hoisting exterior-wall cladding materials aboveground. This development may take on the majority of the risks in the execution of construction, thereby eliminating the need of a labor force and providing improved productivity and safety. This paper presents an example of a certain construction which lent an impetus for us to develop the shuttle system. This article will proceed by first describing the history of the development of the system, then discussing the method overview and features and the effects of system application. Finally it will conclude with future development.

2. HISTORY OF THE DEVELOPMENT OF THE SHUTTLE SYSTEM

2.1. Construction overview of buildings to which the shuttle system was first applied

Figure 1 provides an outline of the buildings.

Construction	:	Steel frame
Building size	:	Two buildings, each being 31 meters in height
Building type	:	Parking towers of elevator type, each for 128 cars
Exterior wall finish	:	An enameled panel with approx. 600mm × 600mm over the entire wall surface



(a) Elevation (b) Planar view

Figure 1. Elevation and planar view.

2.2. Intent of system employment

The planning for the execution of the works by means of the shuttle system commenced with the assembly of 600mm × 600mm (some panels measuring 250m × 2000mm) enameled panels into the number of units required. Each unit was comprised of three vertical panels and four horizontal panels. The assembling operations were performed in workshop, for delivery to the construction site. This system obviously surpasses the conventional system in which all panels must be installed one by one on the construction sites.

As well, if the general method is employed to install exterior wall panels, scaffolding would have to be erected around and along the entire height of the buildings. Due to this procedure, we might have encountered the following limitations and problems;

① The existence of some closely located neighboring buildings did not allow for the installation of scaffolds around the buildings.

② Operations at elevated places without the use of scaffold might cause serious danger.

③ The installation of the panels would require a large crane, for example, with the hoisting capacity of 50 tons if no other effective method is available, which would increase the cost. Also, dangerous operations would have to be performed at this confined site.

We decided that the best solution available to these limitations and problems, was the development and implementation of the shuttle system, a method which is used to install exterior wall panels in a way which enables the installation by sliding them up the buildings.

3. SYSTEM OVERVIEW

The shuttle system provides for a system that repeats the operations ① through ⑧ shown in Figure 3: a set of four electric chain blocks are provided at the four corners of each building which hoist shop-assembled panel units successively, each time together with the stage. This is followed by their installation from the building's top down the wall toward the bottom. This system uses the term "shuttle" as a prefix because the stage moves up and down a building with panel units in it, reciprocating between the ground and the installation positions.

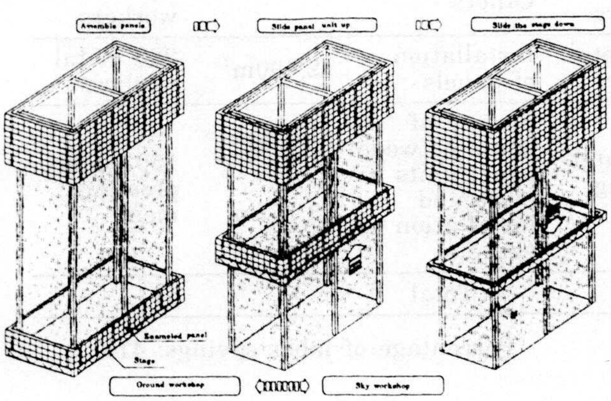


Figure 2. Conceptual shuttle system outline.

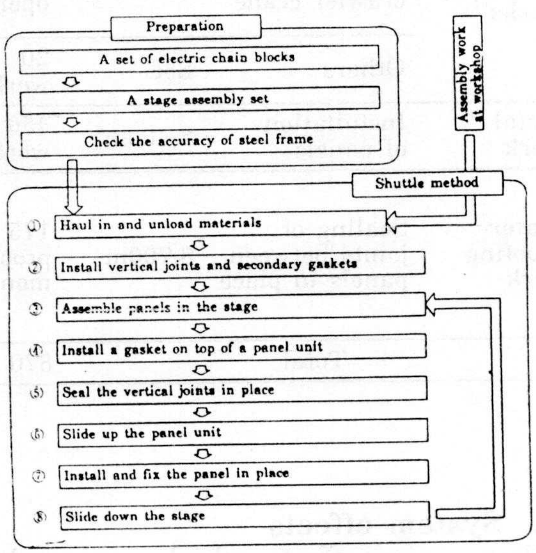


Figure 3. Flow chart.

To enable panel units to be hauled up to the exact installation positions, various sensors were used to automatically measure the horizontal and vertical positions while the panel unit is being slid up, so that the sliding device can be controlled. Sliding operations can be monitored on the display of the computer located in the operation room, in which it is integrated and computer control is performed.

4. SYSTEM APPLICATION EFFECTS

The incorporation of the shuttle system exceeded the conventional installation method in the creation of the following outstanding effects:
① Productivity was enhanced by about 20%.
② Approximately 40% labor savings could be achieved.

This section discusses the breakdown of the 40% labor savings which could be achieved through the mechanization and automation of panel installation operations. The two most important factors which led to the success in satisfactory completion of the buildings' exterior cladding are also discussed. Table 1 compares the shuttle system with the conventional method.

Table 1
A comparison between the shuttle system and the conventional method.

	Conventional method			Shuttle system		
Temporary works		10,330m^2	150 scaffolding men		Set	40 scaffolding men
General temporary works	A 50-ton crawler crane	3 months	75 operators	A 5-ton track crane	2 months	50 operators
	Others	Set	20 workers	Others		48 workers
Metal work	Installation of panels	2,400m^2	450 metal workers	Installation of panels	2,400m^2	225 metal workers
Water-proofing work	Sealing of joints between panels in place	8,700m	175 water-proofing men	Sealing of joints between panel units in place and installation of gaskets	7,680m 3,167m	150 water-proofing men
Total			870	Total		513

Percentage of labor savings: 41%

4.1. System effects

The major effects which were achieved through the field application of the shuttle system are discussed below:

① Success in the achievement of the shuttle system, in which no scaffolds whatsoever are used, could assure an extremely high level of safety.
② Without involvement with operations performed on shaky-exterior scaffolds, on-the-ground assembly of panels could assure improved installation accuracy and quality.
③ The incorporation of various sensors into the measurement system permitted the operation of electric chain blocks through monitor displays in the operation room, until the installation of the last piece of panel unit. This also ensured reduced labor and improved comfort in the carrying out of the administration of the task.
④ The employment of silicon gaskets to seal the horizontal joints between the courses of panel units in place, eliminated the use of both sealing compound and gondolas.
⑤ The use of hanger type slide jigs wherever neighboring buildings were located close to the buildings enabled the entire operations to be performed by means of a 5-ton truck crane, but not by using any larger or heavier crane. This could cut the cost considerably. Other merits include the wider utilization of the confined site and improved operation efficiency.
⑥ A shortened construction period was achieved.
⑦ Since the shuttle system has generality, it can be applied to other similar constructions.

5. FUTURE APPLICATION

In the development stage, we encountered selective difficulties, and events which had never been anticipated. This section elaborates such information that may be useful in the employment of this type of method in the future. When choosing a single device from among many types of vertical carriers, it is necessary to scrutinize it from various angles by comparing its adequacy with that of other carriers. Table 2 compares an electric chain block with a hoist and a hydraulic jack.

Table 2.
A comparison in performance between an electric chain blck, a hoist and a hydraulic jack.

	Comparison item	Electric chain block	Hoist	Hydraulic jack	Comment
1	Work-performing ease	◎	△	×	≪ An electric chain block is of a simple construction and exhibits work-performance ease. ≫
2	Cost efficiency (general)	◎	△	×	≪ For an electric chain block, a variety of inexpensive, multi-use types are available on a lease basis, as well they are cost efficient. ≫

Table 2.
A comparison in performance between an electric chain blck, a hoist and a hydraulic jack.

3	Safety	◎	×	◎	≪ An electric chain block is of a simple construction offering a high level of safety.≫
4	Synchronized control accuracy	◯	◎	◎	≪ An electric chain block will be able to perform synchronized control if using sensors.≫

Specifications of the electric chain blocks for use with the shuttle system	Lifting capacity	Lifting velocity	Quantity used	Gross weight	Stage	One panel unit
	2.8 tons/unit	1.7 m/min	4 units	7.5 tons	3.0 tons	4.5 tons

An electric chain block is used not only by the shuttle system but also by many other methods.

5.2. Horizontal and vertical accuracy control system

As compared with other industries, currently, few general contractors at their construction divisions have industrialized sensors of various types. With the shuttle system, the horizontal and vertical accuracy control system fulfills the role of the brains. The system effectively used various sensors as described on next page:

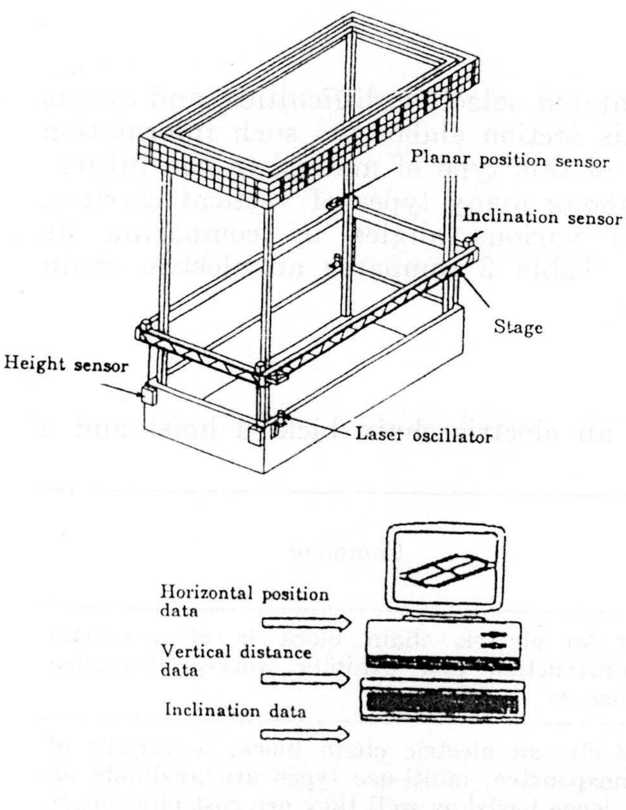


Figure 5. Conceptual illustration.

Photo 1. The state of the horizontal and vertical accuracy control system being in operation.

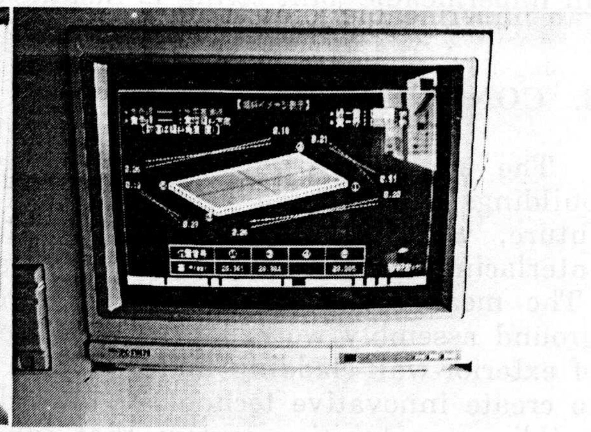


Photo 2. An inclination sensor as displayed on the computer screen.

- Four wire type height sensors were set at the four corners of the stage, for the detection of height.
- Two laser oscillator type planar position sensors were set at opposing points, for the measurement of planar deviation.
- An inclination sensor was provided at each side of the stage, for the measurement of panel distortion.

Measurement results transmitted from these sensors were processed and displayed at real time by the computer located in the field office, so that panel sliding-up and -down operations can be monitored. Up to 1mm of a panel position can be adjusted by remote-controlling each of the four electric chain blocks.

Using the following conceptual illustration and the photographs, the system is described in further detail.

5.3. A gasket to fill a horizontal joint between panel units

Since in principle the shuttle system uses no scaffold whatsoever, how to seal the horizontal joint between panel units gave rise to an issue to be resolved.

To cope with this issue, Fujita Corporation has developed a silicon string gasket. After panels have been assembled to form a panel unit, this silicon gasket is stretched along the top of the full length of the panel unit. Compression of the gasket will occur when another panel unit is butted to the gasket-applied top of the preceding unit, resulting in the creation of impermeability of the joint. Using this method, all impermeable joint strings could be installed before sliding up panel units, thus realizing an absolute no-scaffold method. Figure 6 illustrates the typical way in which an impermeable joint string is installed.

6. CONCLUSION

The shuttle system, we believe, can be applied to such steel-framed buildings as shopping centers, office buildings and sky scrapers. In the future, we will dedicate ourselves to improving the shuttle system by interlacing both an attitude control system and an automatic lifting system. The measurement results derived from the sensors and with an on-the-ground assembly workshop will be used, so that the unmanned installation of exterior-wall-cladding materials can be executed. Also, we will endeavor to create innovative technology toward the realization of a fully automated building construction system that can be generalized to the application to steel-framed buildings, an automatic up-down scaffolding system enabling bolting, welding, to the installation of exterior-wall cladding materials.

Photo 3. The sliding-up of a panel unit is proceeding.

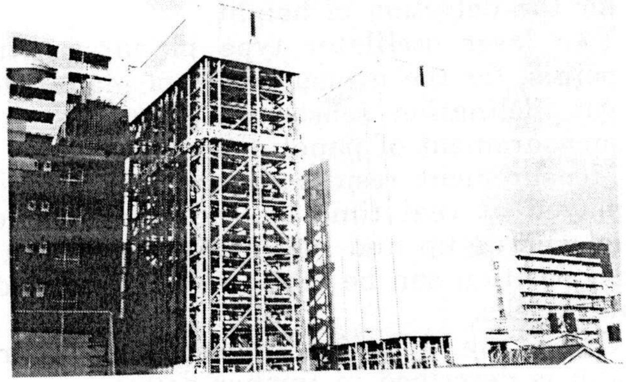


Photo 4. The sliding-up of the stage is proceeding.