Development of an Automatic-oriented Sheltered Building Construction System

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Abstract

In order to meet the increasingly sophisticated requirements for large-scale construction projects, in 1993, Penta-Ocean Construction began to develop a comprehensive system that would facilitate building construction work in all weather with minimum disturbance to the surrounding neighborhood.

We call this system FACES: Future Automated Construction Efficient System.

The system was introduced in 1995 after comprehensive testing and verification of the system's applicability, safety and efficiency, including wind-tunnel and actual-size experiments, Since February 1996, FACES has been employed in the construction of the Nihonbashi-hamacho F Tower in Tokyo. In March 1997,high-rise structure including its penthouses has been completed by the system.

This paper describes how the construction system:FACES worked at the site, featuring original lifting method and automatic conveyance system together with results of the system application to this project.

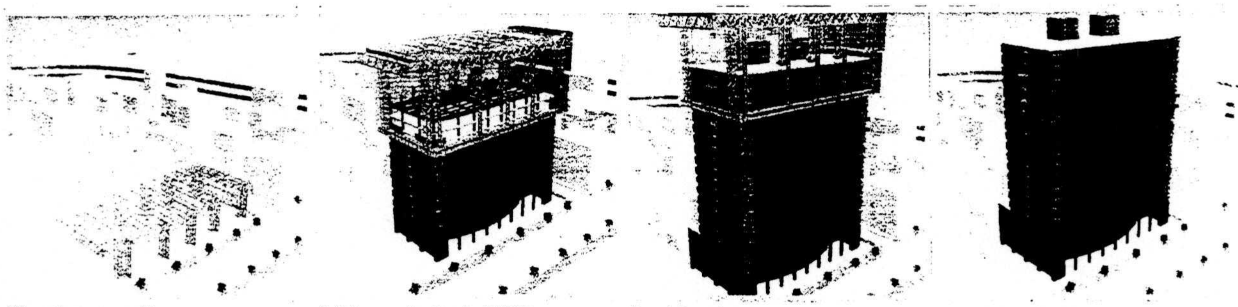
1. Introduction

FACES is a fully integrated and self-contained construction system to achieve the following goals:

- Construction of high-quality buildings
- Reduction of construction time and stable schedule
- Increased productivity through automation
- Integration of information and labor management
- Creation of a comfortable working environment
- Improvement of safety standards
- Making the site less intrusive to the surrounding area
- Reduction of industrial waste and enhancement of resources conservation

In this system, the building area is covered by a shelter called a lift-up frame, and all work is carried out inside this shelter: steel framework, floor slab work, and exterior wall work. When such work is completed in one floor, the lift-up frame can be raised to accommodate construction of the next floor. This process is repeated until construction of the top floor.

Fig. 1 shows the flow of the construction;the system's assembly, execution of work, and disassembly. Fig. 2 shows the overall configuration for FACES.



Lift-up frame assembly | Building construction by FACES | Completion of structure and Lift-up frame disassembly | Completion of building

Fig.1 Construction flow

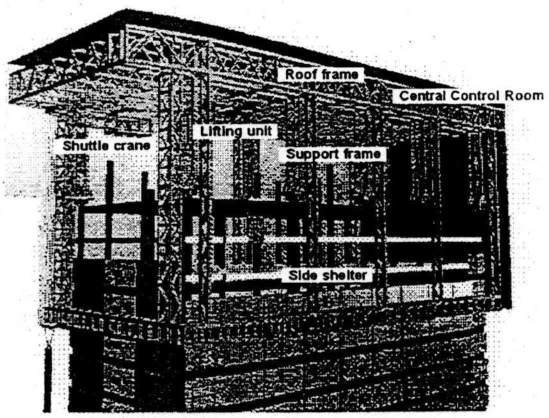


Fig.2 Overall configuration of FACES

1.1 Lift-up frame

The lift-up frame is composed of roof frame, support frames, side shelters, and other essential components (generally referred to as "the frame"), creating a comfortable and all-weather working space for the entire duration of a project.

1.2 Central control room

The central control room is located under the roof frame and acts as the system's brain controlling all automated functions, coordinating lifting phases, telemetry control for frames, and various other tasks.

1.3 Lifting system

The lifting system is composed primarily of 250-ton oil-hydraulic cylinders, upper and lower clamps, and oil-hydraulic units. The cylinders, which are incorporated into the support frames, raise the frame by reacting upon approximately 1/3 of the building columns for lift. These are referred to as supporting columns.

Leveling of the frame during lifting operation is controled by limiting the stroke difference within 5mm among cylinders. At a lifting speed of 2mm/sec. the lift-up frame can be raised to the next floor level in approximately one hour.

1.4 Shuttle crane (automatic materials conveyor)

This overhead traveling crane is capable of traveling, boom turning and shuttling, hook turning, and hoisting. It has a lifting load capacity of 10 tons with turning radius of 6 to 10 meters and hoisting reach of 120 meters.

The optimum conveying route - from material stock yard to designated position - is automatically determined by the central computer, and individual materials are then automatically transported to its installation places. Even for extremely long items, the lifting position of the suspended materials can be arbitrarily controlled by turning the two-hook lifting beam. This eliminates the possibility of lifted material's collision with frames and completed structures.

1.5 Individual techniques for mechanization and automation

In order to improve the efficiency of steel framing work, many innovative techniques have been developed, such as the automatic slinger removal unit, column plumb adjuster unit, automatic welding robots, and multiple-beam lifting equipment. These techniques have made construction easier and shortened the working time as well as improving on-site safety.

1.6 Unitized facilities improve productivity

The unitized facilities such as toilets and prefabricated exterior panels significantly improved overall quality, simplified installation and resulted in the reduction of industrial waste.

1.7 Computer-aided construction

Construction floor supervision, quality control, process control, and safety management functions have been linked by computer to afford the free flow of information throughout the various phases of construction. This enables site managers to continuously make adjustments and improvements as the project progresses.

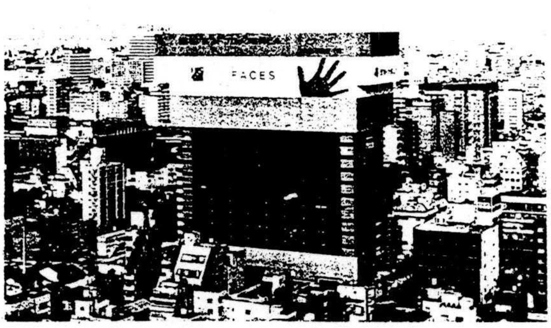


Photo 1 View of the FACES project

2 Site Introduction of the System

2.1 Brief outline of building project

Building name:
Nihonbashi-hamacho F Tower
Construction site:
3-19/20, Nihonbashi-hamacho, Chuo-ku, Tokyo, Japan
Construction period:
19 June 1995 to 31 October 1997
Structure: (See Fig.3)
20 story high-rise tower with 2 story penthouses:
Steel frame construction
2 level basement substructure:
Steel-frame-and-reinforced-concrete composite construction

Site area··················· 3,754 m²
Building area·········· 2,667 m²
Floor area················· 34,876 m²
Max. height············· 85 m

Building use:
Office space, residential, retail shops, community center, parking lot

2.2 Overall temporary facility plan

The application range of FACES encompasses the superstructure of the high-rise tower. Fig.4 shows the site overall plan.

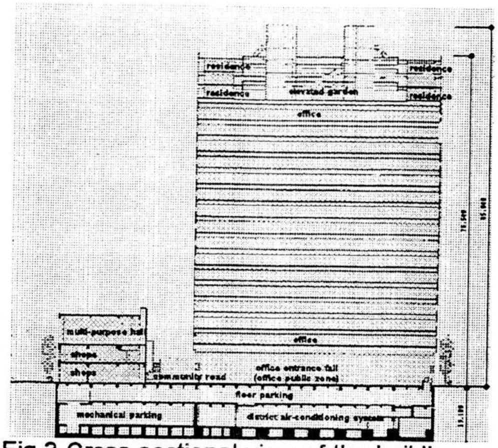


Fig.3 Cross-sectional view of the building

2.3 General procedures

The system can be introduced after completing the earth retaining work, piling of earth-drill piles with erected structural steel column for substructure, and finished ground floor slab. Thereafter, the system member assembly work and top-down construction for substructure are executed simultaneously.

In this way, FACES can avoid time loss in the construction due to the system implementation.

After the lift-up frame is assembled, lifting and conveyance equipment are coordinated and put into use for the actual operation as shown in Table 1.

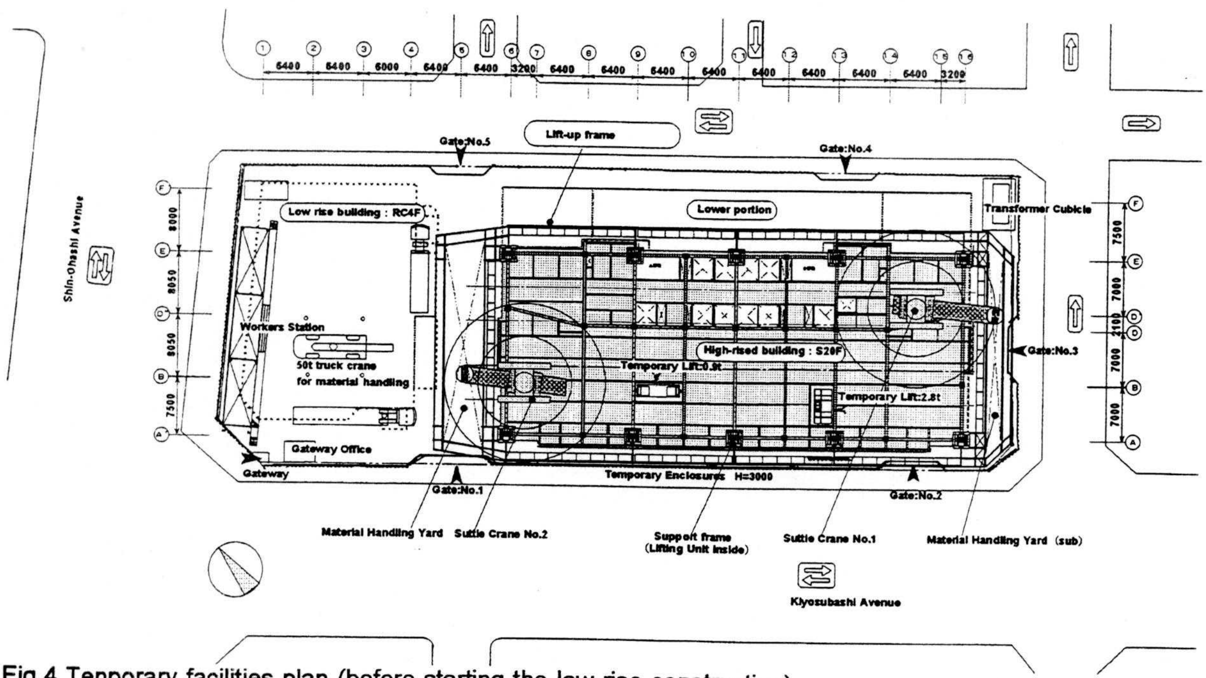


Fig.4 Tenporary facilities plan (before starting the low-rise construction)

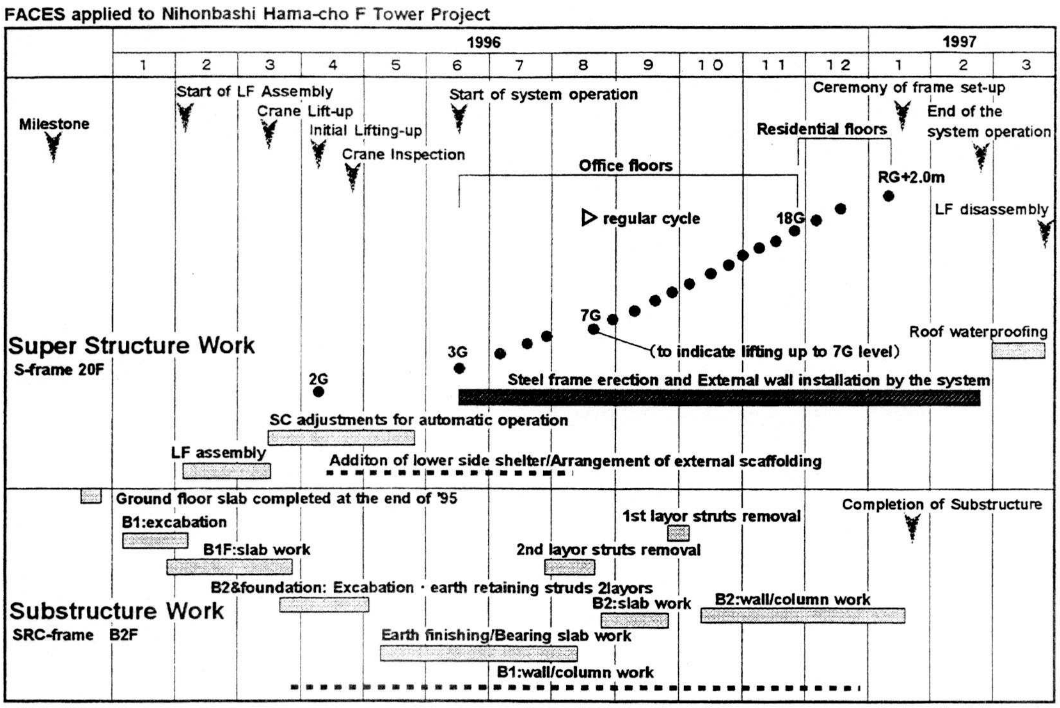


Table1 Work progress

3. Building process and labor-saving techniques

3.1 Construction cycle

Table 2 shows the construction cycle of this system. On Floor N, steel frame erection, welding of supporting columns and girders are carried out in three days. Deck plates are subsequently set up, starting from the completed steel sections.

On Floor N-1, from the second day, column welding and floor bar arrangement are started and completed on the fifth day. While stone wall panels are mounted temporarily on the fifth day, then concrete is placed on the sixth day.

On Floors N-2 and N-3, exterior wall panels are mounted and exterior sealing work is finished during the cycle.

3.2 Automatic slinger removal unit

An electromotive slinger removal unit is installed on the crane's lifting beam, so that the workers can automatically remove the slingers from the erected steel by remote operation without climbing to an elevated location and reduce labor hours. Photo 2 shows the exterior view of the unit.

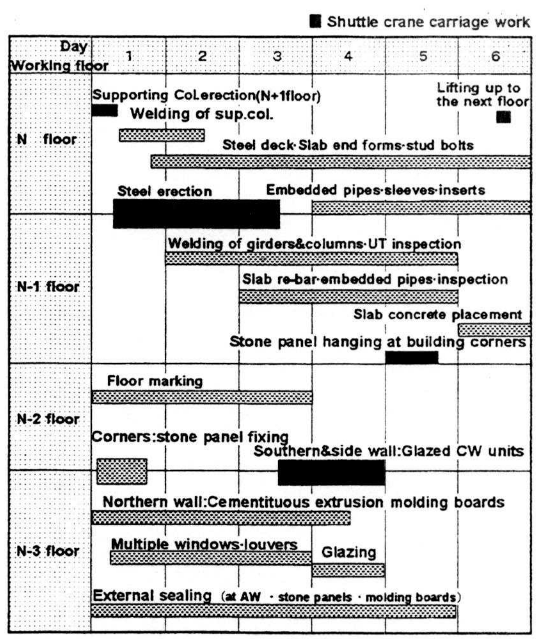


Table 2 Cyclic procedure of construction work

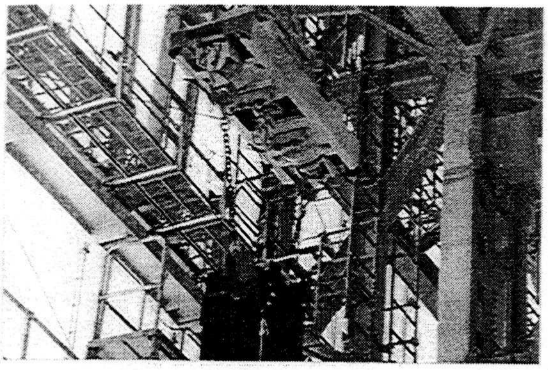


Photo 2 Automatic slinger removal unit
Maximum load: 6tons × 2
Operating frequency: 300times/charge cycle
Unit weight: 12kg × 2

3.3 Multiple beam lifting equipment

This device is used to lift and transport a number of beams from the material handling yard to the designated position at one time. It takes 20 to 25 minutes to install three beams at a time. Compared with single beam transport, the required time is totally reduced by approximately 40%. Photo 3 shows the view of the device.

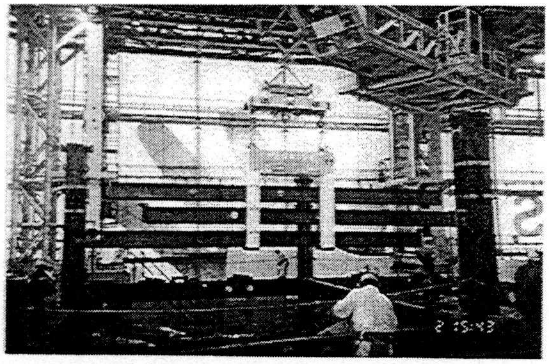


Photo 3 Mulitiple-beam lifting equipment
No. of beams handled: 2 ~ 3 beams
Capacity: 6tons
Beam size: 200 ~ 900 × 150 ~ 300mm

3.4 Automatic welding robots

Robots are used for welding of erected columns (□ 600 x 600 x t25 ~ t50) . Only one welding operator can manipulate a set of two robots for each column as shown in Photo 4. These robots improve welding quality and consistency, and eliminate a strenuous and unpleasant phase of construction.

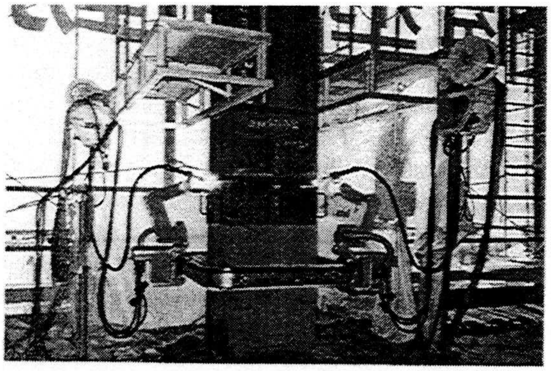


Photo 4 Automatic welding robot for steel columns
Robot: Articulated, 5-axis NC-controlled
Applicable columns: Box/Formed/Round columns
Applicable plate thickness: 19 ~ 80mm

3.5 Unitization and prefabrication

Glass curtain wall units are fabricated in the factory that includes framing, glass insertion, sealing, and fireproof board mounting.

Also, lavatories have been unitized to save installation time and improve its quality. Walls, ceilings, sanitary fixtures, and piping are also prefabricated and are hoisted to the mounting floor by shuttle cranes as shown in Photo 5.

Although the above unitizations can be executed in conventional building site, it is more effective to do it in this all-weather sheltered system because the wall panel installation inside the sheltered wall will not be influenced by wind and there will be no protection needed to shield rest rooms against rainwater and strong wind.

Moreover, this kind of prefabrication and all-weather protection are great factors in minimizing industial waste produced from on-site fabrication and protection materials.

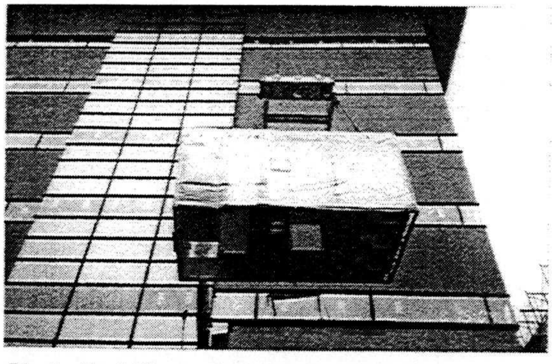


Photo 5 Lifting a toilet unit

3.6 Positive use of side shelter working platform

FACES accomodates exterior scaffolds at the side shelter so that various kinds of wall details can be completed in the shelter. Exterior sealing work can be finished as soon as wall components are installed while in conventional methods, sealing cannot be started unless gondolas become available. Also wall installation such as extrusion moulding boards is quite safer and efficient compared with the work without exterior scaffolds. Fig.5 shows the sectional view of a side shelter scaffolding used for installation of cementitious extrusion moulding boards at the northern side of the building. Photo 6 shows exterior sealing work on side shelter scaffolds for multiple window and stone panel combination part at the corner sections of the building.

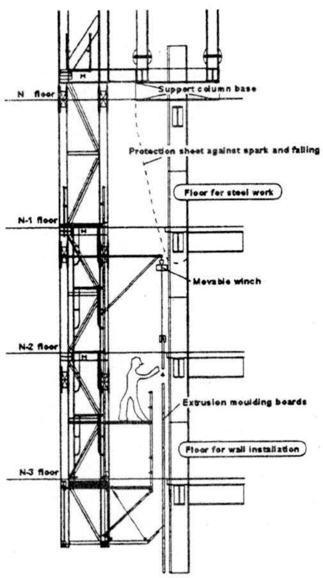


Fig.5 A exterior scaffolding at the side shelter

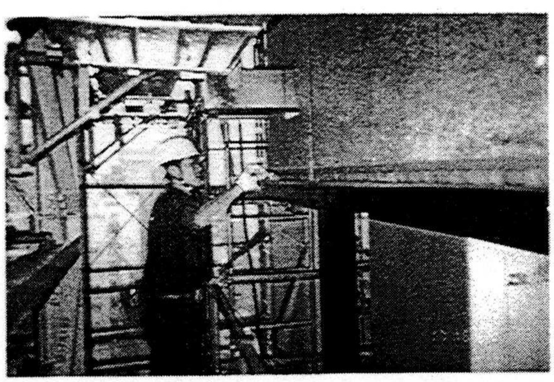


Photo 6 Exterior sealing work on the side shelter scaffolds

4 Basic Components and Techniques

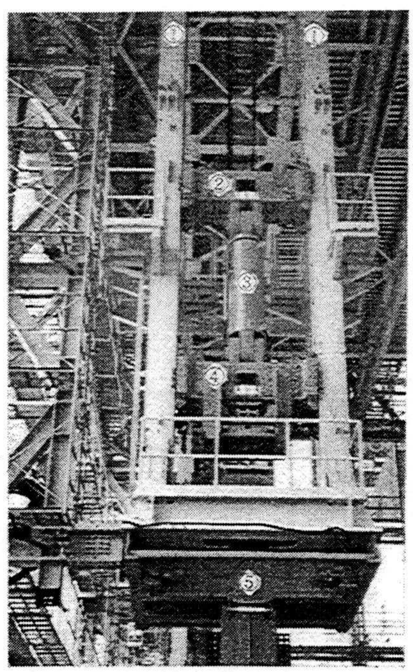
4.1 Lifting unit and lifting up system

(1) Major specifications and configuration

Table 3 shows major specifications of lifting unit, and Photo 7 shows the view of the unit.

The lift-up frame is supported at different points for lifting up operation and building construction work. The frame is supported at the top of each supporting column during lifting up and after lifting, it is put on girder brackets of supporting columns at the height of girders to be erected.

As such, roof supports are composed of space framed members so that they surround the building columns and a vertically movable lifting unit is installed inside this frame. This unit is provided with upper and lower clamps and a 150 tf oil-hydraulic cylinder between them. In this way, the clamp section can be locked by protruding duel pins to the side holes of the ladder supports.



① Ladder supports
② Upper clamp
③ Oil-hydraulic cylinder
④ Lower clamp
⑤ Base supporter

Photo 7 Lifting unit

Oil-hydraulic cylinder : 250tf×700mm stroke
Pin distance of upper and lower clamps : 3,000~3,600mm (holes@600mm at ladders)
Cylinder telescoping speed : 2mm/sec (At no loads : 4mm/sec)
Lift-up time required : 65min./3.75m=story height

Table 3 Lifting unit specifications

(2) Method of lifting up

Fig. 6 shows the lifting procedures. Insertion and drawing out of lock pins, and telescopic motions of a cylinder, are conducted like the behavior of a measuring worm. The frame is raised by giving a reaction to the building column located just beneath the lower clamp. During this stage, base-supporting-box beams (called base supporters) beneath the support frame have horizontally moved as far as the position where girder brackets of newly installed supporting column can be averted. It moves to the column side after it has passed by the girder brackets. Since then, it is slightly lowered and lifting up is finished after the entire frame has been put on the girder brackets on the next floor.

Following the same procedure at 10 units, the lift-up frame can climb up to the next floor for about one hour.

(3) Features

Features of this lifting system are as follows:

1) Since stiffness of each support frame is high, the number of supporting columns used to shoulder system's weight can be reduced to approximately 1/3 of the total building columns on the standard floor. (See Fig. 4)

2) It is unnecessary to raise and lower supporting masts while supporting columns are installed. Therefore, installation can be finished promptly.

3) Since supporting columns can be welded and erected without load disturbance, adjustment of skeleton accuracy can be easily accomplished.

4) Wall anchors for the side shelter are not fixed to the building, but to the support frame base. So, replacement of wall anchors is not required during lifting up.

5) Lower portions of the side shelter can be utilized as exterior working scaffolds as shown in Fig.5.

4.2 Shuttle crane: Automatic conveyance equipment

(1) Major specifications and configuration

Table 4 shows major specifications of shuttle cranes. This equipment is composed of traveling rails, traveling rack, turning frame, shuttle boom, and hook turning ring as shown in Photo 8.

(2) Major functions and features

Major operational modes are hoisting (lifting), traveling, boom turning, boom's telescopic operation, and hook turning. Fig.7 shows these operational modes.

These functions are simultaneously used and materials and members are automatically conveyed from the material handling yard to the mounting position.

The main hoist unit installed in the shuttle boom is a 2-drum type, employing two wire ropes.

The operation panel in the control room, the control panel on the crane, and various sensors are connected through a pantograph of the trolley wires for power supply, mounted on one side of the crane, and through the incoming panel for control and communication cables, mounted on the other side.

In addition, the obstacle detection photo sensors are mounted on crane's outer periphery and monitoring cameras are installed behind the shuttle boom and below the hook turning ring, to serve as safety equipment.

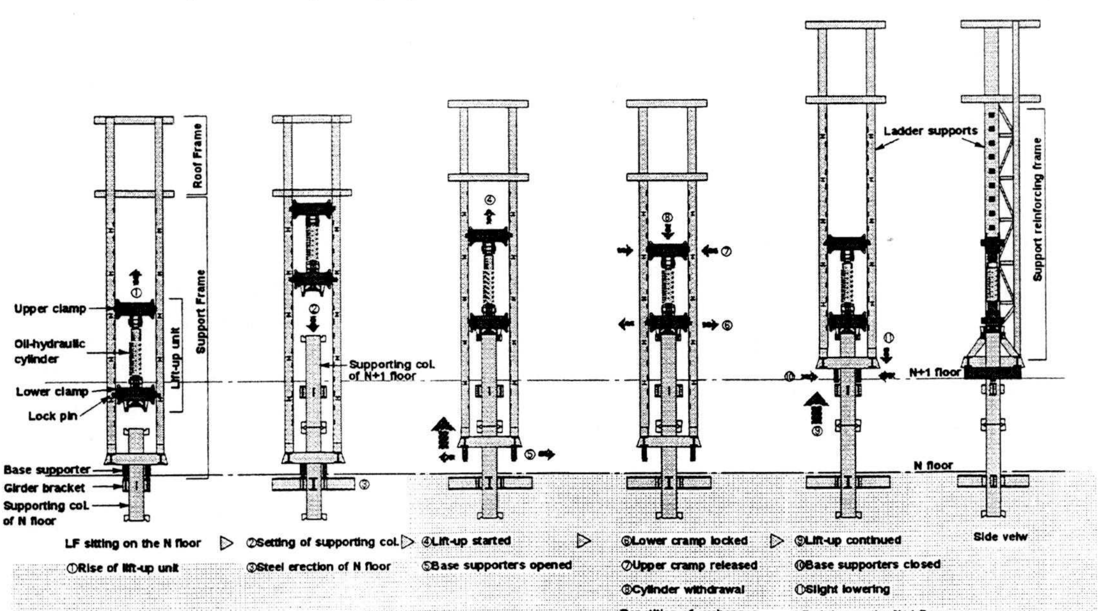


Fig.6 Lifting-up procedure

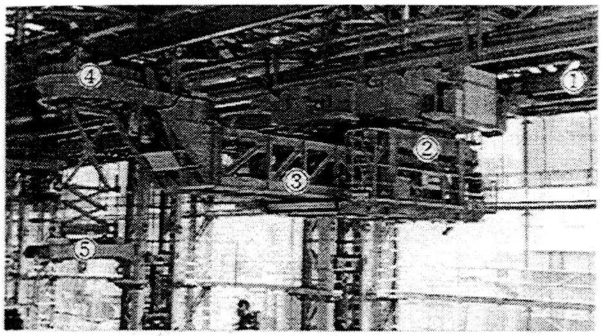


Photo 8 Shuttle crane (Automatic conveyor)

① Traveling rails ② Turning frame ③ Shuttle boom
④ Hook turning ring ⑤ Hook beam

Rated suspension load : 10t	Traveling speed : 20m/min
Boom turning radius : 6~10m variable	Boom shuttle speed : 20m/min
Lift : 120m	Boom turning speed : 1/0.5 rpm
Lifting/lowering speed : 10t－38m/min	Hook turning angle/speed :
5t－50m/min	front±90° /0.5 rpm
No load－70m/min	Creep mode : 7%speed operation
2-hook independent hoisting-lowering speed/stroke : 0.45m/min/0.5m	

Table 4 Shuttle crane specifications

1) Telescopic function (shuttling) of the boom

Using this function, turning radius of the boom can be adjusted within the range of 6 to 10 meters. Unlike other overhead cranes, this crane can afford to expand its conveying area without traveling girders.

2) Lifting position control

For automatic conveyance of girders and such lengthy objects, it is necessary to avoid interference with support frames and installed building columns

Thanks to the hook turning ring mechanism which is newly developed, a turning force can be given to a lifted member. The turning range is ± 90 ° .

3) Establishment of automatic conveyance route

A computer determines the optimum conveyance route that can even reach the mounting position in a manner of avoiding interference with other cranes, lift-up frame, and existing structures. Once the members already installed, it is recognized as existing structures in the established conveyance route. Therefore, such route always conforms to the present progress of erection.

Data from the loaded members such as sizes, mounting positions, etc. are transmitted from the site office to the control room through an optical LAN.

After starting the automatic conveyance, an operator supervise the crane conditions at the monitors such as shown in Photo 9.

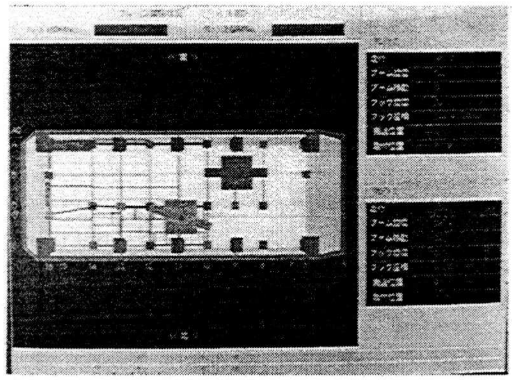


Photo 9 Crane monitor during automatic conveyance

4) Inclination adjustment for lifted materials

Wire ropes are lifted or lowered at a creep speed. Thus, horizontal adjustment becomes easy and fast to achieve, when mounting girders and exterior wall panels.

This is because the wire ropes have respective motor generated cylinders that allow free adjustment of each wire rope independently.

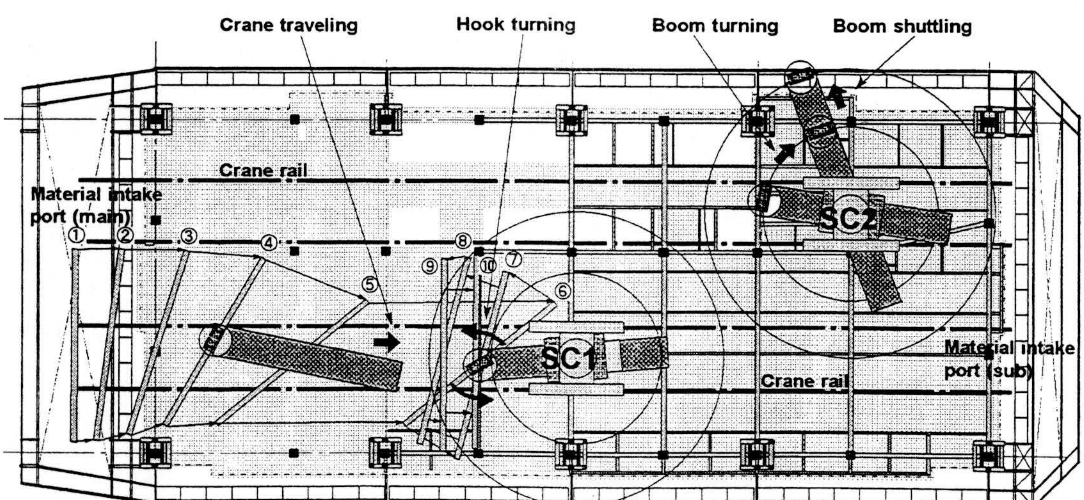


Fig.7 Operational modes of shuttle cranes and Automatic conveyance of a long girder illustrated

4.3 Site information technologies

A supervisory system is used on the working floor and quality control is carried out, in order to share necessary construction data. Fig. 8 shows computerized site information system.

(1) Working floor supervisory system

Conditions of lifting and conveyance control are supervised not only in the control room but also in the site office for the safe and assured promotion of work by FACES. With this increased communication and feedback, arising problems, if any, can be dealt with promptly.

(2) Quality control

Using handy terminals, quality inspection data are electronically transmitted to the on-site data base.

(3) Safety control

Effective labor-saving features of the system include personnel ID cards and the use of electronic media for work diaries and the immediate issuance of work instruction sheets.

(4) Process control

Installation work sequence for columns and beams and progress of the work according to the working plan can be examined on the computer display. Therefore, it is easy to promote working plans and to execute proper modification if necessary.

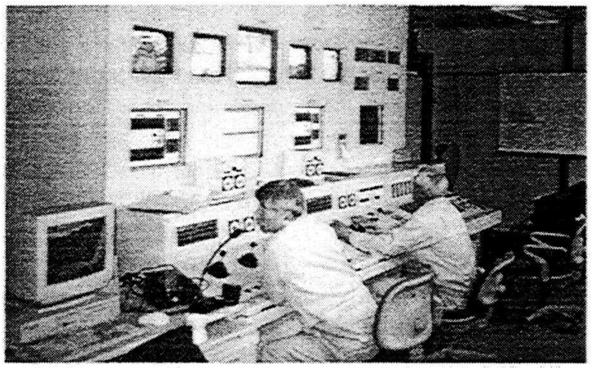


Photo 10 Central control room

5 Effects of the system

Through the operation of FACES as a sheltered building construction system, we have recognized the effectiveness of the system as described below.

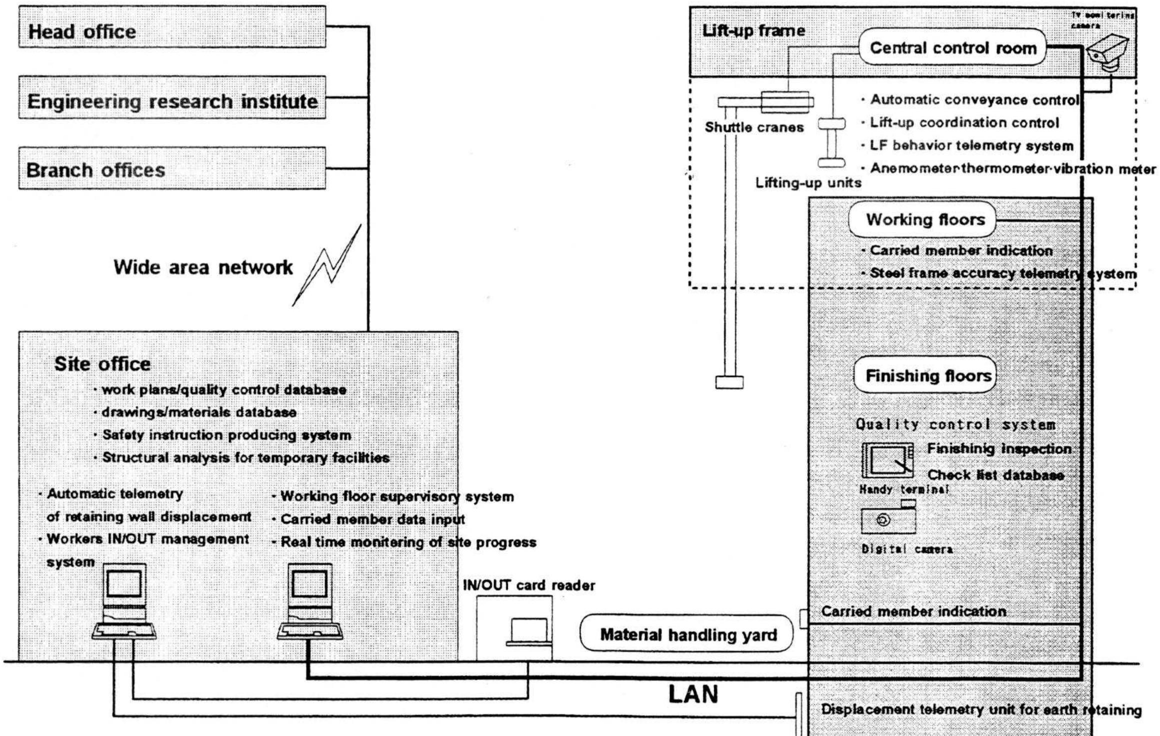


Fig.8 System diagram for site information technologies

5.1 Effects of all-weather features

Modification of work due to climatic changes on an ordinary site can affect the actual construction working schedule and other activities on the site, such as reviewing and rearrangement for the work plans. However, the adoption of an all-weather system has resulted in effective labor saving in the site progress management, since the coordination of work is still effective even during adverse weather conditions.

In addition, quality of the building has been improved in terms of welding, exterior wall sealing work processing, floor concreting, and others.

5.2 Labor saving in execution of works

As a result of unitizing and active use of side shelter scaffolds, labor saving has been achieved in the actual work as shown in Table 5. This saving has been also achieved in terms of individual techniques of mechanization and automation, such as multiple beam lifting equipment.

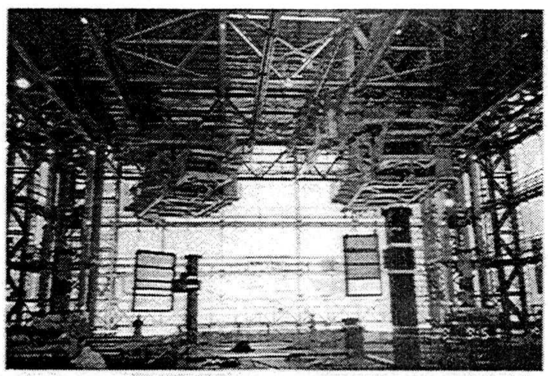


Photo 11 Glass CW conveyed by shuttle cranes

Working location ／scale(standard floor)	Anticipated efficiency of conventional methods	Efficiency performed	Labor-saving factor at site
Glass Curtain Wall	Knock-down system	Full unit system	
245 m²	2～3 m²／man · day 1)	12 m²／man · day	**1/4～1/6**
Toilet room	conventional method	System toilet unit	
19 m²、23 m² 2rooms	64men／standard floor	15men／standard floor	**1/4**
Moulding board installation	Non-scaffold method	Exterior scaffolding work at the side shelter **(FACES)**	
164 m²	3～4 m²／man · day	6.4 m²／man · day	**2/3～1/2**
Exterior sealing	Using gondola	Exterior scaffolding work at the side shelter **(FACES)**	
390m(size15×10etc)	15m／man · day	40m／man · day 2)	**1/3**

1) Frame assemly only, not inclusive of glazing and sealing work
2) Includes installation of water drainage pipes in 40 positons inside seals

Table 5 Labor-saving results

5.3 Reduction of construction time

Since work could be continued even on rainy days, progress of high-rise building was advanced by approximately one month. As a result, leveling of manpower was possible in all processes, due largely to advancing the progress of the works.

The construction time can change according to individual site conditions and construction requirements. Our studies have shown that for this system, a high-rise building with approximately 20 floors appears to be a benchmark for the reduction of construction time. For over 30 floor buildings, it would be much effective in the time reduction.

5.4. Working environment

The enclosed construction perimeter provides workers with an all-weather working environment that is safe and efficient. Sky lighting and side shelter scaffolding of the lift-up frame are but several of the many outstanding features of this innovative system.

5.5 Peripheral environment

The exterior image of the FACES construction format has given a new and brighter image to urban construction sites.

6 Future development

In the future, construction methods are expected to become increasingly automated and computerized, utilizing vast data bases of information to increase efficiency and lower the negative impact on both the natural environment and the immediate surrounding area.

Through application to a variety of projects, further development will be carried out until the FACES becomes typical one.