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Subjects: Construction
Structural Engineering

Keywords: Construction
Steel
Technology

Publication Date: 2004

Original Publication: CTBUH 2004 Seoul Conference

Paper Type:

1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

The Automated Building Construction System for High-rise Steel Structure Buildings

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Abstract

The Automated Building Construction System (ABCS), which was developed for constructing high-rise steel structure buildings, applies the concept of factory automation to the construction site and allows much of the work to be done in a factory. It applies automation, robotics, and computer technology to building construction. The ABCS integrates the Super Construction Factory (SCF), which provides all-weather warehouse facilities, with automated conveyer equipment and a centralized computer control system.

The ABCS has been used four times in about ten years. Each time, it improved productivity, quality, safety, working conditions, and surrounding environment compared with the conventional method. In this paper, we present three applications of the ABCS for practical high-rise buildings. Through these experiences, we have adapted the ABCS to various building designs and construction conditions, and have improved the system. As a result, the ABCS construction period and labor required have been reduced.

Keywords: Steel Structure; High-rise Building; Factory Automation; All-weather; Production Management

1. Introduction

Obayashi Corporation has been researching and developing an automated building construction system for high-rise steel structure buildings since the 1980s with the objectives of shortening the construction time, reducing total cost and rejection, improving productivity and quality, increasing safety, and enhancing the working conditions and surrounding environment.

High-rise steel structures are usually built using tower cranes. The quality and progress of work executed by this method can be easily affected by weather conditions. The need to work at elevated levels is another problem, and the aging of construction workers and shortage of skilled workers are aggravating problems. The Automated Building Construction System (ABCS) was developed in 1989 to solve these problems and increase productivity. The ABCS employs an erection system for installing steel members, external panels, etc. which differs from a typical conventional tower crane system, and provides a working space protected from the elements by a shell. The ABCS also incorporates various integrated automation and information technologies.

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In 1993, the ABCS was used for the first time to build a medium-rise, ten-story building as a partial trial. Subsequently, it was used a further three times in ten years. This paper reports on these applications of the ABCS to construct practical high-rise buildings.

2. Outline of ABCS

2-1 Basic System Configuration

The principal components of the ABCS are a structure that encloses the working space, a parallel delivery system (PDS) and an integrated management system. The structure enclosing the working space, Super Construction Factory (SCF), comprises a roof and surrounding walls and is supported by columns erected on top of the steel columns erected as part of the building frame. The PDS consists of material lifts or high vertical hoistway telphers and overhead traveling cranes. This equipment performs vertical transportation to the floor on which construction work is being carried out (construction floor), and horizontal transportation on the construction floor. The ABCS integrated management system consists of three subsystems: the production management system, the equipment operation management system and the machine control system.

2-2 Construction Process

At the first stage of the ABCS, the SCF is assembled and the PDS is installed. At the second stage, the typical floors are constructed inside the SCF

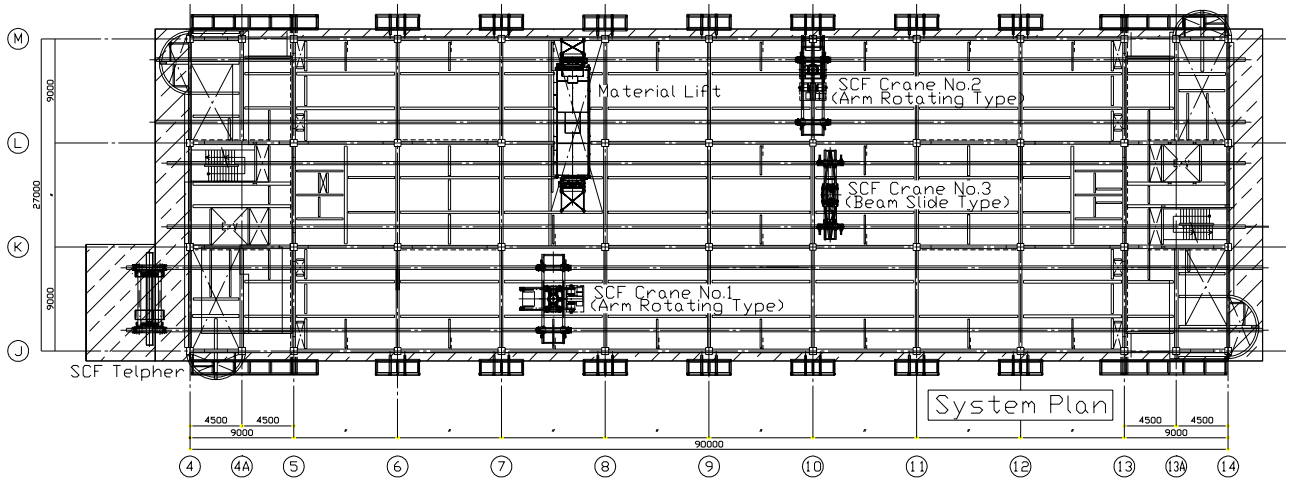

Fig. 1. System Plan of SCF

one by one. At the final stage, the SCF's main structure is lowered to become part of the building and the temporary part of the SCF is dismantled.

During the typical floor construction (TFC), building frame work and exterior work can be carried out in the SCF, regardless of the weather conditions. When the construction of one floor has been completed, all of the climbing equipment built into the support column lift the SCF up to the next level. The TFC proceeds by repeating these steps. The system plan is shown in Fig. 1 and the cross section of the system is shown in Fig. 2, for the fourth application as an example. In Figure 2, the Nth floor is installing the girders and beams floor, and the (N-1)th floor is the construction floor, on which building frame work is being carried out. The (N-2)th and (N-3)th floors immediately below are the exterior work floors.

2-3 Super Construction Factory

2-3-1 Roof and walls

The roof and walls, which are covered with weatherproof sheeting, form an all-weather working space. The framework of the SCF consists mainly of two floors which include the top floor of the building.

2-3-2 Climbing system

The support columns (climbing supports) are erected on top of the steel columns of the building and penetrate the SCF frame, and the uppermost part of each column is equipped with a climbing equipment. Each equipment has two hydraulic jacks and all of them are centralized controlled.

2-4 Parallel Delivery System

2-4-1 SCF cranes

The SCF crane is set below the roof and has two types. One has a lifting capacity of 13 tons and is equipped with a rotating arm; the other has a lifting capacity of 7.5 tons and the beam slides laterally.

On the construction floor, the SCF cranes perform the horizontal transportation and installation of steel columns and beams, precast concrete floor slabs, and external paneling on the side walls of the building. Special holding devices are used to rig the steel columns and beams for lifting, and unrigging is performed by remote control.

2-4-2 Elevating equipment

The material lift is used to lift steel columns and steel beams packed on special pallets, various floor slabs, reinforcements, finish and equipment work materials, etc., from the first floor to the construction floor. By installing the lift inside the building, there

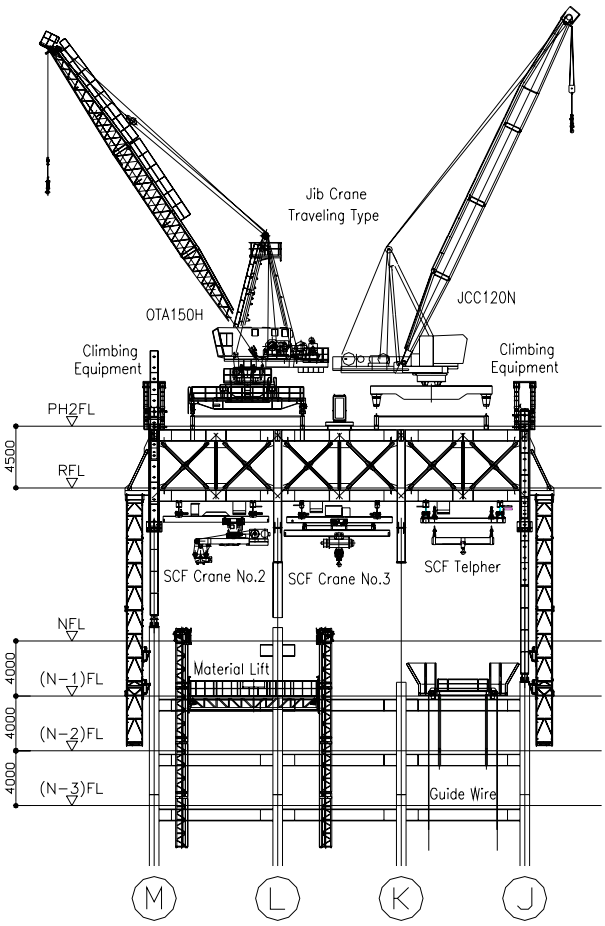

Fig. 2. Cross Section of System

Table 1. Overview of Projects

	Project N1	Project J	Project N2
Number of Floors	B2F/26F/PH2F	33F/PH2F	B1F/37F/PH2F
Maximum Height	110m	138m	155m
Total Floor Area	79,752m^2	47,766m^2	105,572m^2
Building Use	Office	Hotel	Office
Plan Shape	Rectangle갔90m*27m갔	Rectangle with Setback갔67m*16m갔	Rectangle갔90m*27m갔
Structure	Under 3rd Floor: Steel-Frame RC		Under 3rd Floor: Steel-Frame RC
	Above 3rd Floor: Steel-Frame	Aboveground: Steel-Frame	Above 3rd Floor: Steel-Frame
Core Arrangement	Both Ends	Both Ends	Both Ends
Steel Column	Bracket Type	Bracket Type	Non-bracket Type
Girder Connection	High Tension Bolt	High Tension Bolt	Welding (High Tension Bolt)
Floor Slab	Half Precast Concrete	Half Precast Concrete	Deck Plate (Flat Type)
External Facing	PCCW, ACW, Louver	PCCW (with Escape Balcony), AW	PCCW, ACW, Louver
Construction Period	Oct. 1997 to Jan. 2000 (28 months)	Aug. 2000 to Mar. 2002 (19.5 months)	Oct. 2002 to Jan. 2005 (27.5 months)
Neighborhood	Three Railroads	A Railroad, Famous Resort	Two Railroads, N1 Building

are wide openings from the first floor to the top floor, whereas if the lift is installed outside the building, some of the exterior finishing work must be done after the lift is dismantled.

The SCF telpher was developed for the fourth application. It is set below the roof and its winch and control equipment are set on the lower floor of the SCF. The rails for traveling are common with the SCF crane. While being lifted, materials are subject to swinging and rotation by strong winds, so they were prevented from colliding with the installed external walls by fixing guide wire ropes from ground level to the (N-1)th floor.

2-4-3 Jib crane (traveling type)

The jib cranes are installed and can travel on the SCF. They are used for installing external panels, dismantling the temporary portion of the SCF and performing the rest of the finishing work.

3. Applications

3-1 Application Details

The ABCS was announced to the press in 1989, and has been applied four times in about ten years. The details of the four applications are shown in Fig. 3. After the development of elemental technologies and new productions for about two years, we used the method to construct a medium-rise building for the first time in 1993, called project S. We proved that the ABCS was an effective method, but found that some parts of the system needed to be improved for practical high-rise buildings, and so developed and produced new elemental technologies. We have applied the new method three times since 1998, called project N1, project J, and project N2 in turn. Through these projects, we have adapted the ABCS to various building designs and different construction conditions, and have improved and changed the system.

3-2 Overview of Projects

The three projects are outlined in Table 1. The system planning of the ABCS is greatly affected by the building design and the construction conditions. In terms of design, the core arrangement, girder connections, floor slab and specifications of external facing are especially influential.

Projects N1 and N2 involved the same architectural planning for the twin towers of a high-rise office building of almost the same design and shape, so the most of system contents in project N1 could be reused

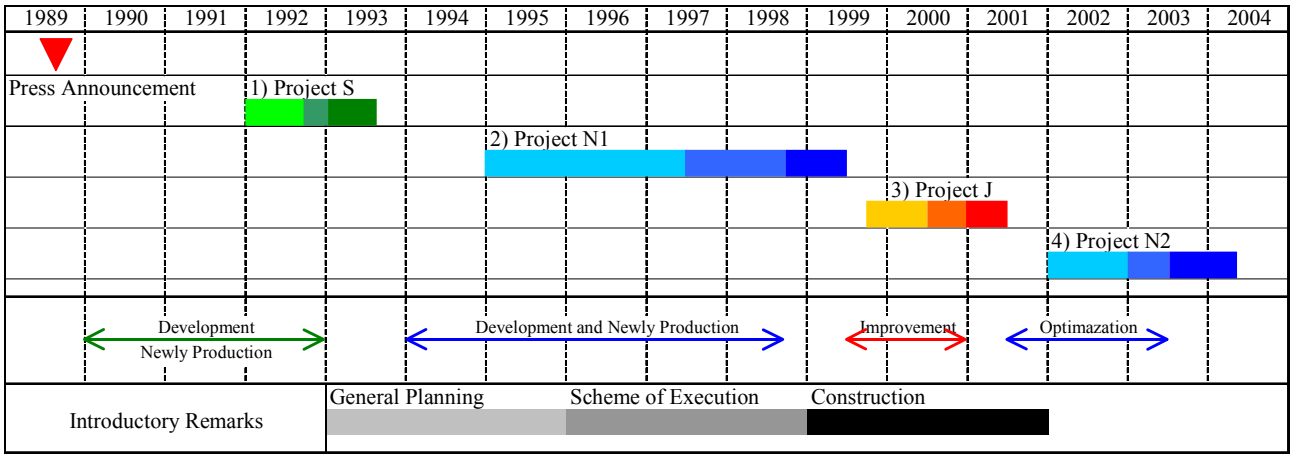

Fig. 3. Details of Applications

Table 2. Comparison of Three Systems

	Project N1	Project J	Project N2
Characteristics of System	Newly Production	Simplized System	Optimized System
		Priority for Steel Work	Reuse Material Using Project N1
Important Item	Building Quality	Shorter Construction Period	Cost Down
Exterior Finish Work in SCF	All	Nothing	Partial (Face of Gable End)
Construction Floor Area	2,700m^2? 9floors (8 to 26)갹51,300m^2	1,100m^2? 6floors (5 to 30)갹28,600m^2	2,700m^2? 0floors (8 to 37)갹81,000m^2
Story Height	4.0 meters	3.4 meters (Partially 3.8 meters)	4.0 meters
SCF	RF-PH2F갉2,200ton갊	31F-32F갉1,600ton갊	RF-PH2F갉2,200ton갊
	W36m*L102m*H30m	W18m*L75m*H21m	W32m*L105m*H23m
Lift Up Equipment	22 sets	16 sets	22 sets
Outer Scaffolds	Full Type (Fully Around)	Partial Type (Around Colomn)	Partial Type (Around Colomn)
(Setting Floors)	4 Floors {N to (N-3) floor}	2 Floors {N to (N-1) floor}	2 Floors {N to (N-1) floor}
SCF Crane	13tons / Arm Rotating Type*2units	13tons / Arm Rotating Type*2units	13tons / Arm Rotating Type*2units
	7.5tons / Beam Slide Type*1unit		7.5tons / Beam Slide Type*1unit
Elevating Equipment	Material Lift*2units (Inside)	Material Lift*1unit (Outside)	Material Lift*1unit (Inside)
(Arrangement)			SCF Telpher*1unit (Outside)
Climbing of Material Lift	Every Floor	Every Two Floors	Every Two Floors
Jib Crane Traveling Type	JCC-120N*1unit	JC-150H*1unit	OTA-150H*2units
	U-100*2units (for Dismatling SCF)	JCC-120N*1unit	JCC-120N*1unit
Tact Schedule (Plan)	6 Days	4.5 Days	6 Days
Inside Scaffold	Self-lifting Work Platform Machine	Light and Folding Work Platform	Folding Work Platform
(Moving Type)	(Self Running)	(Hand Carrying)	(Rollaway)
Beams Packing	Site	Steel Fabricator's Factory	Site
Others	Automatic Control for SCF Crane	Anti-Collision	Anti-Collision
	Hoistway Telpher for External Panel	Control System for SCF Crane	Control System for SCF Crane
	Column Welding Robot		

in project N2. However, two points of the structural design (non-bracket type column and deck plate slab) were adopted in project N2 to reduce the cost of building materials. It was especially important to improve the building quality in project N1, and to reduce the total cost in project N2.

Project J had a very small site area and very short construction period, so it was especially important to shorten the work time. It was a high-rise hotel and required more finishing work than an office building. The external walls had escape balconies that were too large to transport and install easily in the SCF.

3-3 Comparison of Three Systems

We planned the most suitable system for each project. The three systems are compared in Table 2, which shows that the ABCS can be adapted to various building designs and construction conditions by changing the setting plans of the surrounding walls and the elevating equipment. We tried to simplify the system planning because we wanted to reduce the ABCS construction period and labor required compared to the preceding application.

In project N1, the building quality was improved by fully covering the surrounding walls to the (N-3)th floor and completing the exterior finishing work by using the outer scaffolds in the SCF. The SCF of project N1 is shown in Fig. 4. After the SCF is lifted up to the next level, the completed external facings of one floor appear under the surrounding walls. However, the total construction period of the project was very short, so it was effective to make the outer scaffolds simple and to cover the surrounding walls to the (N-1)th floor, because it was much faster to assemble and dismantle the simple outer scaffolds than the full type. The external panels can be installed using jib cranes outside the SCF simultaneously with the progress of steel work inside the SCF. In projects J and N2, we limited the outer scaffolds for steel work and set them only around the columns in the longitudinal direction.

We decided the arrangement of material lifts for each project depending upon the remaining part of the interior or exterior finishing work. We set the material lift inside the building in preference to the exterior finishing work in projects N1 and N2 which were offices, but set them outside the building in preference to the interior finishing work in project J which was a hotel. As it is important to save labor in order to reduce cost, we developed the SCF telpher in project N2 in order to reduce the assembly, dismantling and climbing labor, and to reduce the remaining work after dismantling. The SCF telpher is shown in Fig. 5, which shows that the exterior work along the SCF telpher's hoistway is not delayed at all.

4. Construction Results

We present chiefly the comparison of construction results in projects N1 and N2 in this chapter, because both of them have the mostly same building design and shape, and project condition.

Fig. 4. Surrounding Walls of SCF

Fig. 5. SCF Telpher

4-1 Assembling and Dismantling SCF

It is necessary to plan to minimize the time for assembling and dismantling the SCF, because while the SCF is constructed or disassembled, other construction activities directly below and for installing the ABCS's equipment and temporary materials must be suspended. The period required for projects J and N2 was about 30 to 50% shorter than for project N1 mainly because of making the surrounding walls partial and simple.

The labor per weight (LPW) for assembling and dismantling the SCF was used to compare projects N1 and N2, as shown in Fig. 6. The LPW of project N2 was about 35% lower than that of project N1. In particular, the LPWs related to the surrounding walls and elevating equipment were greatly reduced.

4-2 Typical Floor Construction

The tact schedule during the typical floor construction (TFC) was planned principally in consideration of the SCF climbing steps and the work efficiency of the PDS. Careful consideration was given to sharing of the construction area because the steel frame work inside the SCF and exterior work outside the SCF were done simultaneously in parallel. The tact schedule of project N2 is shown in Fig. 7. On the Nth floor, the steel frame work and the deck plate slab installation appear twice. The reason for this is that the central span, as shown in Figs. 1 and 2, was constructed first, and then the two spans on both sides of the central span were constructed. Since the step at which loads from the SCF are supported on top of the steel columns in the central span was necessary in the SCF climbing procedure, the lowering of the SCF exists in the tact schedule. After the construction of one floor is completed, the SCF is lifted up as height as one floor and the next tact is ready. These steps were planned as a six-day process, and they did take six days and five days at the last stage because of skillfulness and adaptability.

The labor per floor area (LPFA) for TFC was used to compare projects N1, N2 and N1 (conventional method) as shown in Fig. 8. The data of project N1 (conventional method) shows the practical execution results for the part using crawler cranes on the ground or jib cranes on the SCF. The LPFA of projects N1 and N2 was about 15% lower than that of project N1 (conventional method). Some changes of the structural design made little difference in the LPFA of projects N1 and N2.

4-3 Total ABCS Construction Period

The period of assembling and dismantling the SCF is longer than that of tower cranes in the conventional method. But during the TFC by the ABCS, the steel work and the exterior finishing work

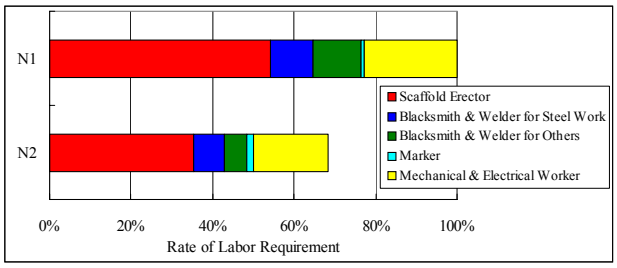

Fig. 6. Comparison of Labor Per Weight

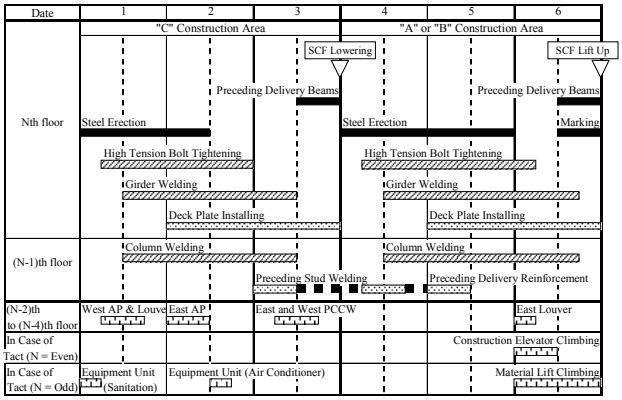

Fig. 7. Tact Schedule

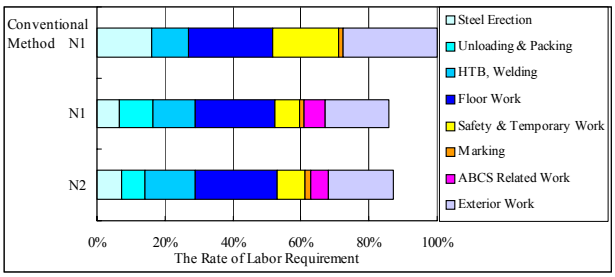

Fig. 8. Comparison of Labor Per Floor Area

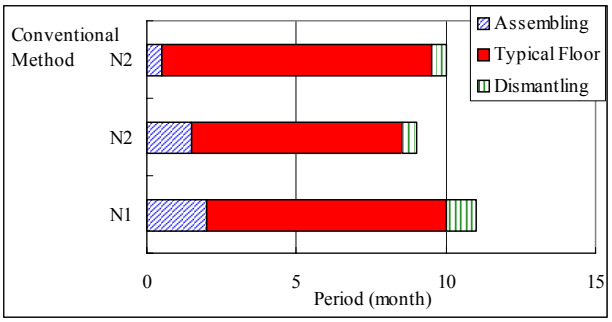

Fig. 9. Comparison of Total Construction Period

can progress simultaneously in parallel, so the period of TFC by the ABCS is shorter than that by the conventional method. As the number of typical floors increases, the ABCS method more effectively shortens the construction period. Further, the works in the SCF are completed respectively on every story, so the exterior work and the skeleton work of the floor slab can be completed early on as high a story as possible. This greatly reduces the total construction period (TCP), because the interior finishing work can be started early.

The key to successful implementation of the ABCS, therefore, is to shorten the time required for assembling and dismantling the SCF. A comparison of the TCP related to the ABCS is shown in Fig. 9. The data of project N1 show that the number of typical floors is the same as in project N2, and the data of project N2 (conventional method) show the estimated value at an early step of the execution planning. Thanks to the system improvement, the TCP of project N2 was about two months shorter than that of project N1, and we estimated that the TCP of project N2 could be made about one month shorter than that of project N2 (conventional method). The period of TFC in project N1 could be made about a month shorter than that in project N2 (conventional method). The number of standard floors of project N1 was too small to obtain the full effect of shortening the TCP in the numerical analysis.

4-4 Working Conditions and Surrounding Environment

4-4-1 Working conditions

In the ABCS construction projects, a questionnaire survey about the working conditions in the SCF for

Fig. 10. Inside View of the SCF

some of the construction workers involved was conducted during each project. Many workers in different categories, including multi-skilled workers, scaffold erectors, blacksmiths, welders, exterior finishing workers and equipment workers, were surveyed. The questions concerning the necessity of roof and work efficiency improvement showed positive evaluations, indicating that the workers appreciated having the roof and improved working conditions. An inside view of the SCF is shown in Fig. 10. There are few temporary materials inside the SCF.

4-4-2 Surrounding environment

The sites of the three projects were next to a railroad, a famous resort and office buildings where many people worked, and the surrounding walls prevented all flying objects and falling accidents. The SCF covered with weatherproof sheeting did not give a strong impression of the part under construction.

5. Conclusion

We obtained four effects in projects S and N1: improvement of productivity, quality, work conditions and surrounding environment. In each application, we analyzed the construction results in detail, and fed back the results to system planning of the next project. As a result, we reduced the ABCS construction period and labor each time in projects J and N2. We need to expand the flexibility of application, develop elemental technologies and promote information technologies in the future. We have tried to apply the ABCS to many high-rise buildings with various designs and projects with difficult conditions as a superior choice to the conventional method. Finally, we thank all members related to the development, the improvement or the applications of the ABCS.

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