APPLICATION OF THE AUTOMATED BUILDING CONSTRUCTION SYSTEM USING THE CONVENTIONAL CONSTRUCTION METHOD TOGETHER

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

This paper describes the fifth application of ABCS to a 22-story office building, called project O. The building shape of project O is wide and its plan view is square. We examined the building part of the SCF and compared several application plans in terms of the construction period, the construction cost and so on. As a result of the examination and the comparison, we decided to build the SCF partially including the center core of the building, by simultaneously combining the ABCS and the conventional construction method.

Keywords : Steel Structure, High-rise Building, Factory Automation, All-weather, Welding

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 the total cost and waste, 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. Further problems include the need to work at elevated levels the aging of construction workers, and the shortage of skilled workers. 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 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.

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 to construct practical high-rise buildings whose plan view were rectangular a further three times in ten years [3]. This paper reports on the fifth application of the ABCS to construct a 22-story office building. The building shape is wide and its plan view is square with a center core arrangement for the first time.

2. OVERVIEW 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 and overhead traveling cranes. This equipment performs vertical transportation to the floor on which construction work is being carried out (working floor), and horizontal transportation over the construction floor. The ABCS integrated management system consists of four subsystems: the production management system, the equipment operation management system, the machine control system and the 3D survey system.

2.2 Construction Process

At the first stage of the ABCS, the SCF and the PDS are assembled. At the second stage, the typical floors are constructed inside the SCF one by one. At the final stage,

Figure 1. Perspective of Building Constructed by ABCS

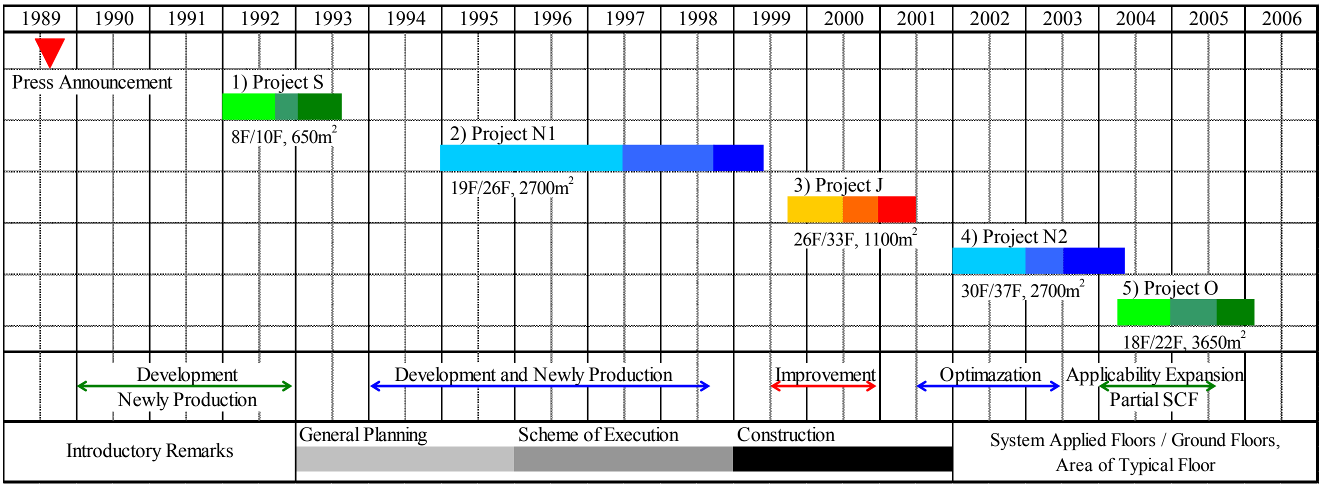


Figure 2. Details of Applications

Table 1. Outline of Project O

Number of Floors	B1F/22F/PH1F
Maximum Height	99m
Total Floor Area	82,451m^2
Building Use	Office
Plan Shape	Square（60m*60m）
Structure	Under 2nd Floor : Steel-Frame RC
	Above 2nd Floor : Steel-Frame
Core Arrangement	Center
Steel Column	Non-bracket Type
Girder Connection	Weld and Bolt (with Horizontal Haunch)
Floor Srab	Deck Plate (Flat and Keystone Type)
External Facing	ACW (Glassed), Louver
Construction Period	Oct. 2004 to Dec. 2006 (27 months)
Neighborhood	A Railroad, Building (Occupied)

the main structure of the SCF is lowered to become part of the building and the temporary part of the SCF is dismantled. The image of each stage is shown in Figure 1.

During the second stage, the typical floor construction (TFC), steel 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 lifts the SCF up to the next level. The TFC proceeds by repeating these steps [1].

2.3 Progress of ABCS

The ABCS was announced to the press in 1989, and has been applied five times in about ten years. The details of the five applications are shown in Figure 2. 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 except the newest application, 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 whereas we have lowered gradually the automatic level of the system [1], [2], [3].

3. OUTLINE OF PROJECT

3.1 Outline of Project

The fifth application, called project O, is outlined in Table 1. It is an office building as part of a plan that includes two other buildings in a large-scale urban renewal area: a condominium and an apartment. The system application planning of the ABCS is greatly affected by the building design and the construction conditions. In terms of design, the area of the typical floor, the core arrangement, and specifications of the external facing are especially influential. Of the latest four projects applied to practical high-rise buildings, project O has the widest area of typical floor and the fewest number of typical floors. Moreover, its plan view is square and it has the structural center core arrangement for the first time of the latest four applications. The structural cores of the buildings of all past applications were arranged at both ends and their plan view were rectangular. We tried to apply the ABCS to project O in order to extend the applicability of the system to more varied designs and shapes of buildings.

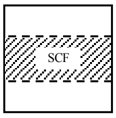
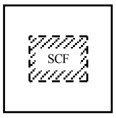
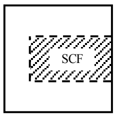
3.2 Construction Process

The construction and completion of project O will take 27 months. This period is normal in Japan today, but we took just six months to construct the typical floors. However, in project O, the external facings are aluminum curtain wall units which are light weight so we decided not to use the PDS of the ABCS and selected the mini crane for the work of the setting the exterior on the floor slab concrete. As a result, we decided that the exterior work would be clearly separated from the construction process of the ABCS. It was therefore expected that the steel frame work schedules without exterior work would be shorter than those with exterior work. Moreover, we had to minimize the time for assembling and dismantling the SCF. So, we set the targets of one month to assemble the SCF, about 4.5 months to construct the steel frame work for the typical floor, and half a month to dismantle the SCF.

Table 2. Comparison with Past Application

Times	Project Code	Assembling Term (month)	Dismantling Term (month)	Weight of SCF (ton)	Area of SCF (m^2)
2nd	N1	2.0	1.0	2,200	3,670
3rd	J	1.0	0.5	1,600	1,350
4th	N2	1.5	0.5	2,200	3,360
5th	O	1.0	0.5	1,000-1,500	1,000-1,500

Table 3. Comparison in Detail of Three SCF Plan

Planning Type (ABCS Application Area)		Plan "A" (Center Belt)		Plan "B" (Only Structural Core)		Plan "C" (Core + Eastern Area)	
Area of Building or SCF Solid Line : Building Dotted Line : SCF		↑ North 		↑ North 		↑ North 	
Lifting Machine (Vertical Transportation)		Jib Crane*2units Material Lift*1unit		Jib Crane*2units		Jib Crane*2units Material Lift*1unit	
SCF Crane (Horizontal Transportation)		Rotating Type*2units Slide Type*1unit		Rotating Type*2units Slide Type*1unit		Rotating Type*2units Slide Type*1unit	
Evaluation of Conveyance Ability		4		2		4	
Comparison Item	Construction Method	Quantity	Percentage	Quantity	Percentage	Quantity	Percentage
Application Area (m^2)	ABCS	1,710	47%	830	23%	1,270	35%
	CCM	1,940	53%	2,820	77%	2,380	65%
Steel Member (pieces/floor)	ABCS	205	60%	141	41%	173	50%
	CCM	138	40%	202	59%	170	50%
Welding Length (m/floor)	ABCS	6,950	64%	4,300	40%	5,625	52%
	CCM	3,925	36%	6,575	60%	5,250	48%
Evaluation of Execution Quantity		3		2		5	
Synthetic Evaluation		3.5		2		4.5	

4. APPLICATION PLANNING

4.1 SCF Installation Area

We examined the covered area with the SCF of project O and compared the actual results of the latest three applications in terms of the construction period, the area of the SCF and so on. The results are shown in Table 2. If we installed the SCF over the whole building, we would not be able to complete assembling and dismantling the SCF within the target periods. Therefore, we decided to install the SCF partially including the center core of the building. There were so many openings at the part of the center core that the SCF could prevent the leaking of much rain to the lower floors under construction by the ABCS and there were so many steel frame members was so many that it was suitable to execute using the PDS of the ABCS. We knew from past application results that for project O, it was reasonable that the area of the SCF was from 1,000 to 1,500 square meters as regards the construction period. Various plans were compared in detail in terms of the ability of machinery to handle the lifting and carrying of material and the execution quantity, as shown in Table 3. In terms of the execution quantity, we balanced the number of steel members and total welding length per floor both the SCF installed area and the area without SCF. As a result of the examination and comparison, we selected plan "C" which scored the highest in the evaluation. The inner area with the SCF was constructed by the ABCS and the outer area without the SCF was constructed by the conventional construction method (CCM). Both of them involved each other and progressed simultaneously in parallel.

Table 4. System Structure and Specification

SCF		W29m×L44m×H4.1m, Total Weight : about 1,200ton
Climbing System		12units, Two Hydraulic Jack/unit, Max Power : 1,960kN/unit
SCF Crane		Arm Rotating Type, Max Weight : 13ton, Winching Height : 15m
		Beam Sliding Type, Max Weight : 7.5ton, Winching Height : 16m
Material Lift		Max Lifting Weight : 13ton, Max Speed : 70m/min
Jib Crane		Max Lifting Weight*Rotating Radius : 230ton*m (Traveling Type)
Management System		Construction Management System (for Welding with RF-ID tags)
		Equipment Operation Management System
		Machine Control System (for Climbing System)
		3D Survey System (for Steel Frame and the SCF Displacement)

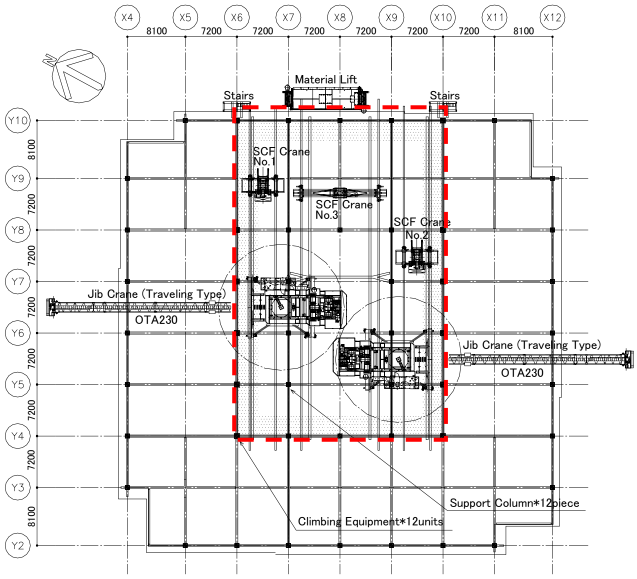


Figure 3. System Plan of SCF

4.2 System Plan

The system plan of project O is shown in Figure 3 and the cross section of the system is shown in Figure 4. The system structure is specified in Table 4. In Figure 4, the Nth floor is where the girders and beams floor is being installed, and the (N-1)th floor is the working floor, on which steel frame work is being carried out. The system structure for the ABCS are described in detail bellow.

4.3 Principal Mechanical Equipment

4.3.1 Super Construction Factory

1) Roof and surrounding walls

The SCF had consisted of the roof and surrounding walls until the fourth application, which were covered with weatherproof sheeting. The framework of the roof consists mainly of two floors including the top floor of the building. However, there were no surrounding walls and only stairs in project O because the walls interfered with the carrying of material by the jib cranes on the SCF and made it hard to erect the steel columns and girders around the boundary of the SCF. Therefore, the SCF did not form an all-weather working space in project O.

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 climbing equipment. Each piece of

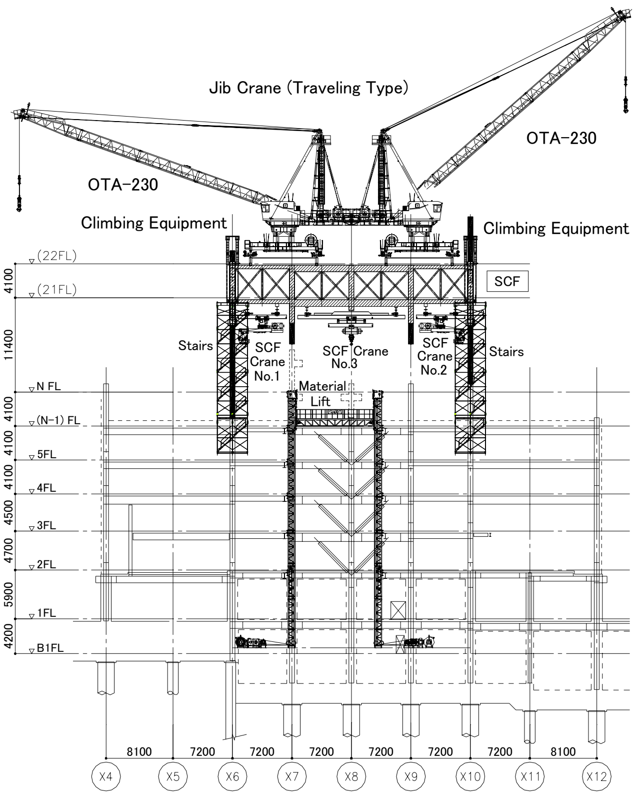


Figure 4. Cross Section of System

equipment has two hydraulic jacks and all of the equipment is centrally controlled by the machine control system.

4.3.2 Parallel Delivery System

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, and the other has a lifting capacity of 7.5 tons and the beam slides laterally. The SCF cranes perform the horizontal transportation and installation of steel columns and beams over the working floor. Special holding devices are used to rig the steel columns and beams for lifting, and unrigging is performed by remote radio control.

2) Elevating equipment

The material lift is used to lift steel columns and steel beams packed on special pallets, various deck plate slabs, reinforcements, finish and equipment work materials, etc., from the ground level to the working floor. Because the lift is installed outside of the building, some of the exterior finishing work must be done after the lift is dismantled.

3) Jib cranes (traveling type)

The jib cranes are installed and can travel on the SCF. They are used for the steel frame work and for installing of the precast slabs at the outer area, carrying the various materials from the ground level to the inner area and dismantling the temporary portion of the SCF.

4.4 Construction Management System

We have progressively changed the contents of the management system using useful new technologies or tailoring it to the needs of each project [1]. We first tried to apply the system to site welding management as a trial to confirm its effectiveness. RF-ID tags were used for this system as a tool for writing the welding and testing records.

The equipment operation management system prevents collisions among the SCF cranes and jib cranes. This is necessary because the SCF cranes can overhang the spans of one another and the bodies of jib cranes interfere with each other or climbing equipment during rotation. The operation is based on the cranes' displacement or movement using the CAD data of the SCF.

The machine control system controls the operations of the climbing system. The climbing operations of the SCF are controlled from an operating console installed in the control room on the SCF.

The 3D survey system was used for measuring the erecting and adjusting positions of steel columns and the displacement of the SCF. It was improved in terms of measuring automatically, and sequentially selecting points of the SCF, and using personal digital assistants (PDA) as the operation terminals with radio remote control function.

5. CONSTRUCTION RESULTS AND DISCUSSION

5.1 Assembling and Dismantling the SCF

5.1.1 Assembling the SCF

There were wide open ceilings on the third and fourth floor and the typical floor starts from the fifth floor in the architectural planning and design. However, the construction by the ABCS started from the third floor. This was why we lowered the working height while assembling the SCF and lowered the kind of crawler type cranes used for assembling. When planning the construction, we could reduce the load resistance of the temporary working platform and hence reduce the cost of installing them. There are no surrounding walls but the steel frame work, such as welding, was increased. As a result of the construction, it took one month to assemble the SCF and install the PDS, and we could finish almost completely according to the scheme of execution.

5.1.2 Dismantling the SCF

The duration of disassembling the SCF could be shortened, because there are no surrounding walls. It took about two weeks to occupy the jib cranes on the SCF for dismantling the SCF, so we regarded the term of disassembling the SCF as half a month. The weatherproof performance is lowered without the surrounding walls but the approach is effective for a project where the construction site is narrow and the construction period needs to be reduced. Working safety while dismantling the SCF is improved because there is the outer area constructed by the CCM as a working floor around the SCF.

5.2 Typical Floor Construction

5.2.1 Standard Schedule

The standard schedule of project O was made based on the results of the past projects, and the steel members and welding length per floor. The schedule for an odd number of floors is shown in Figure 5 and the construction area corresponding to the schedule is shown in Figure 6. Areas

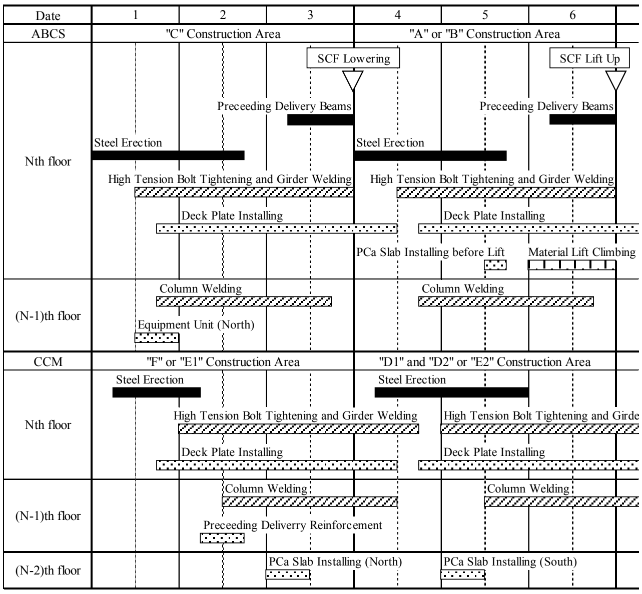


Figure 5. Standard Schedule (Six-day Process)

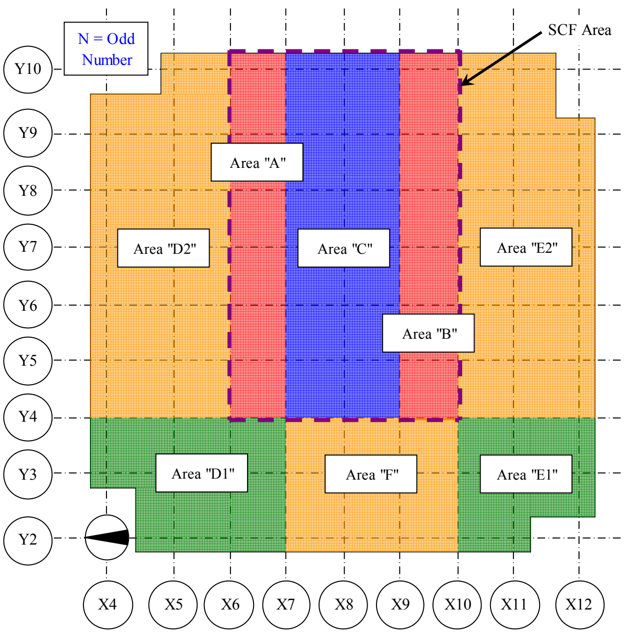


Figure 6. Construction Area

A, B and C were inner areas constructed by the ABCS and areas D1, D2, E1, E2 and F were outer areas constructed by the CCM. We constructed the inner areas ahead of the outer areas because we had to complete the construction of the inner areas in order to lower or climb the SCF on schedule. Moreover, we could adjust working processes of the outer areas even if the schedule had delay factors such as weather conditions. After the construction of inner areas is completed, the SCF is lifted up to the height of one floor, ready for the next schedule. These steps were planned as a six-day process. Although this was somewhat complicated, workers gradually became accustomed to the schedule as they built up their skills repeatedly at every floor.

5.2.2 Shorter Schedule

After several repetitions, the workers became familiar with the schedule and the welding length per floor

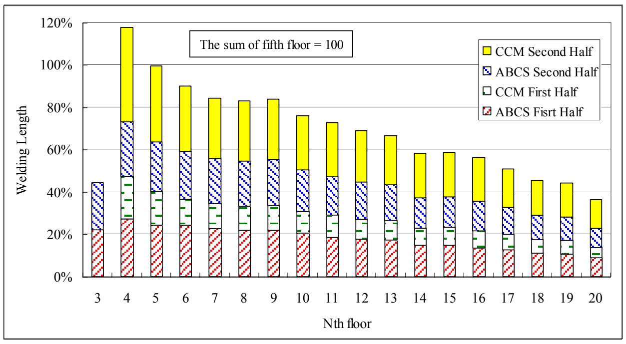


Figure 7. Welding Length

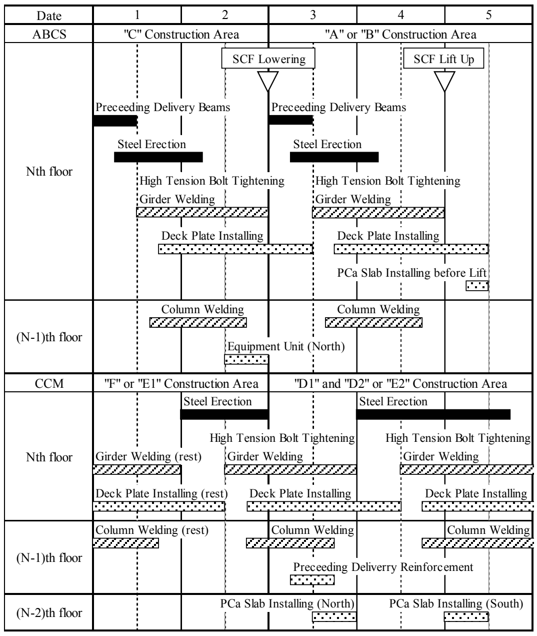


Figure 8. Shorter Schedule (Five-day Process)

decreased gradually. The transition of welding length per floor is shown in Figure 7. We reduced the schedule and decided to start a shorter schedule from the eleventh floor based on the working hours per day and welding length per floor. The shorter schedule is shown in Figure 8. This schedule was planned as a five-day process and the first half of this process was one day shorter.

5.2.3 Labor Yardstick

The labor related to the ABCS per floor area for the TFC was compared the past projects as shown in Figure 9. The labor rate shown in this figure is relative to the total value for project N1 equal to 100. The sum of the labor related to the ABCS for project O was the smallest of the four latest projects, although they had different designs and site conditions. This is why the daily work of the scaffolders could be made roughly constant and the PDS did not require much man power for maintenance.

5.2.4 Total Typical Floor Construction

We define the sum of the period for assembling the SCF, the TFC and dismantling the SCF as the total construction period (TCP) of the typical floors by the ABCS. We could finish the TCP almost completely according to the scheme of execution. A comparison of the

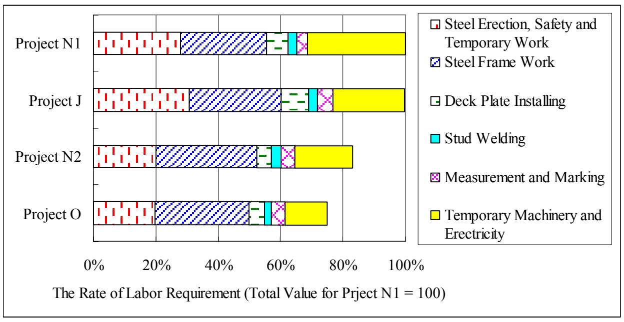


Figure 9. Comparison of Labor Per Floor Area

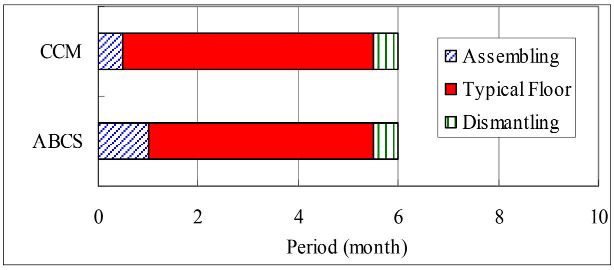


Figure 10. Comparison of Total Construction Period

Photo 1. Inside View of SCF

TCP is shown in Figure 10. The data for completely CCM show the estimated value of the execution planning and mean the periods of assembling and dismantling as those for tower cranes. The figure shows that as the number of the typical floors increases, the TCP of the ABCS becomes shorter than that of the CCM. Although the number of floors was the fewest in the latest four projects, the TCP of the ABCS was equal to that of the CCM. Therefore, we estimated that we can reduce the TCP of the ABCS below that of the CCM if there are more than 20 typical floors.

5.3 Another Effect

An inside view of the SCF is shown in Photo 1. The SCF could not perfectly weatherproof on the working floor without the surrounding walls, but could protect against light rain with only the roof: work that was sensitive to rain was not affected and continued for several hours.

The building being constructed by the ABCS is shown in Photo 2. Each work was completed on each floor when

Photo 2. Building of Project O under Construction

the ABCS was applied, and the work after the floor slab skeleton work could be started earlier than in the case of CCM. In Photo 2 the concrete is placed on the (N-4)th floor and exterior panels are installed on the (N-6)th floor. The ABCS helped to compress the whole process including the finish work of the TFC.

The building constructed by a special construction method as the ABCS attracts a great deal of attention. Therefore, the building owner would get the propaganda effect under construction when we install the sheets shown the advertisement of the project on the flank of the SCF.

6. CONCLUSION

We applied the ABCS partially using the conventional construction method (CCM), together for the first time to project O which had the widest and shortest building in the latest four applications with structural center core. The results of project O can be summarized as follows.

1) The TCP of the ABCS was equal to that of the CCM though the number of the typical floors was fewest in the latest four applications.
2) The sum of the labor related to the ABCS for project O is the smallest in the latest four applications.
3) The ABCS contributed to compress the whole process of the TFC because each work after the steel frame work was completely finished on every one floor.

Finally, we thank all members related to project O.

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