The Development and Application of an Automatic Building Construction System Using Push-Up Machines

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Abstract

The "AMURAD" system developed by Kajima Corporation is a so-called "building factory". The first to fourth floors function as a factory where low level construction work is performed utilizing integrated construction information. When one floor is completed, it is pushed up by special computer-controlled jacks. The first application of this system was at a condominium construction project in Nagoya implemented by Kajima Corporation.

This paper gives an outline of the AMURAD system and describes the results of its application.

1. Introduction

In order to enhance its international competitiveness, Japan's industrial sector is expediting the improvement of its production systems centering on computer-driven information integration, mechanization and labor saving, and the sector is earning an excellent evaluation on the international front for its excellent production systems.

In the construction sector, which is said to be a typical example of a labor-intensive production system sector, attention is focusing on the tardiness of steps to improve the work environment and the demanding nature of the work load compared to other industries. In addition, various other problems are emerging such as a lack of skilled workers and the reluctance of young people to work in the sector.

As one attempt to solve these problems, Kajima has developed an original automatic building production system (known as the AMURAD system). In this system, a fixed construction factory site is located in the lower floor levels of the site which continuously constructs the building using a push up method to elevated the floors built in the factory. This system was employed in the construction of a Kajima employee residential condominium in Nagoya.

This paper gives a report including an outline of the AMURAD Construction System, the actual situation surrounding the construction work in this project, and the results of the application of this system.

2. Outline of the AMURAD system and plans for it's application

1) Outline of the automatic construction system

One core aspect is that in this automatic construction system, unlike the conventional production systems in which the building is progressively built up from the ground floor, the reverse system is employed in which each floor is built starting from the roof and top floor and working down floor by floor to the lower floor levels where construction work is carried out. The floors are assembled and completed at the lower levels and pushed up in sequence, floor by floor. As a result, continuous repeated work operations can be performed in the factory area in the lower floor levels resulting in an automated construction system. Fig.1 shows this construction process.

The lower floor levels of the building under construction function as a fixed construction factory at ground level. As a result, various work processes involving structural members, utility and external works, and interior partition works, are implemented in parallel on predetermined work floors. Thanks to this, it is possible to construct a new floor underneath the completed floors. Moreover, as the completed floor are at the top of the structure, a pleasant, all-weather work environment is provided within the construction factory interior.

2) Outline of the building in this project

The first building this system was applied to was a Kajima employee housing condominium in Nagoya. This was a building with 9 floors above ground (height of 27 meters), and a total floor area of 3,408 square meters. The structure was SRC (steel encased reinforced concrete). For the structural members, precast materials (hereinafter referred to as PCa) were used for each area such as columns, girders, residential area floors, balconies and passages.

3) Work plans

(1) Temporary structures and machinery/equipment.

Fig.2 shows the machinery and equipment developed and fabricated for installation and utilization within the construction factory in this project. Here, we will give an outline of these machinery and equipment units.

a. Push-up machines (Z-UP)

The key factor in this construction system is the push-up machines. The loading arms which support the column edge brackets are smoothly propelled upwards by a rotating screw mechanism, and lift up each floor of the building under construction one by one. In this construction project, one push-up machine was located at each of the ten columns. The units at each of the four corners had a lifting capacity of 400 tons, and those at the central section had a capacity of 600 tons.

b. Structural member handling machine (Z-HAND)

This machine travels on rails set into the ground level construction floor which run in the girder direction. It installs structural members (PCa columns, steel girders, PCa girders, PCa floor slabs) at the required position by moving its upper body section out 3.5 meters at right angles to its rail base. This facilitates circular movement, vertical movement, and sliding movement to slant the materials and effect fine slide positioning adjustment. The maximum capacity of the Z-Hand is 5 tons and a human operator effects wireless remote control.

c. Material handling machine (Z-CARRY)

A monorail facility is located to the south of the building within the fixed factory section rack. The Z-CARRY unit moves in three dimensions and travels laterally using a traverser. It transports materials for eight residential units which are located at the third and fourth floor level during construction work. When the controls are operated at the ground station, the Z-CARRY unit automatically moves to the front of the designated residential unit.

The loading capacity of this automatic transportation machine is about 1.0 ton including the cage weight. The maximum dimensions of the cage are as follows: W;1.0 × H;1.0 × L;3.0 (m). The average time for one transportation cycle (round trip) was about 17 to 18 minutes.

(2) Process plans.

Work on this project started on December 21st, 1995. Work was implemented in the sequence of excavation, foundation work, and machinery assembly and set-up including the push-up machines, etc. From about the middle of March 1996, the 9th floor (top floor) and roof section were constructed as one floor section. Then, on April 3rd, the first push-up operation was implemented. Subsequently, the work proceeded in cycle stages (at a speed of eight days per floor), and was carried out simultaneously in the construction factory on each work

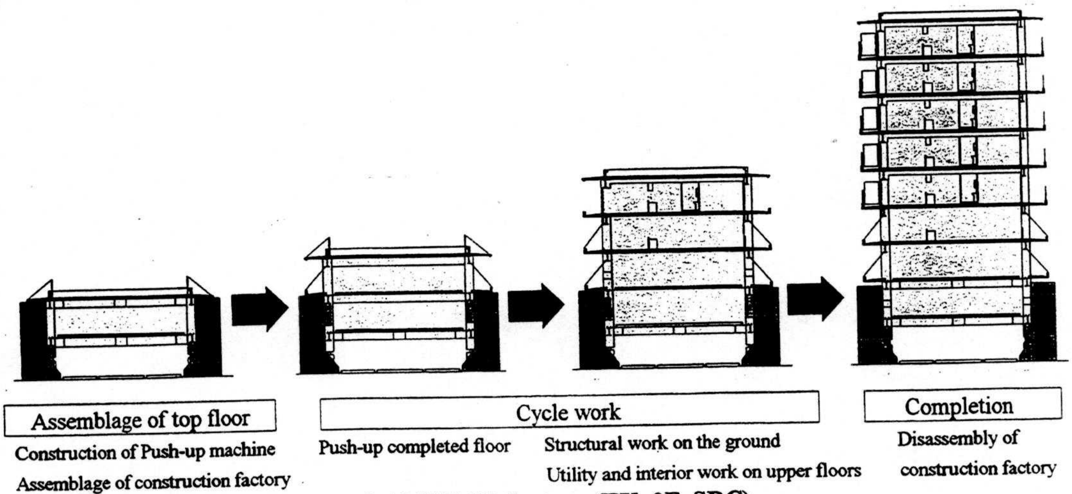
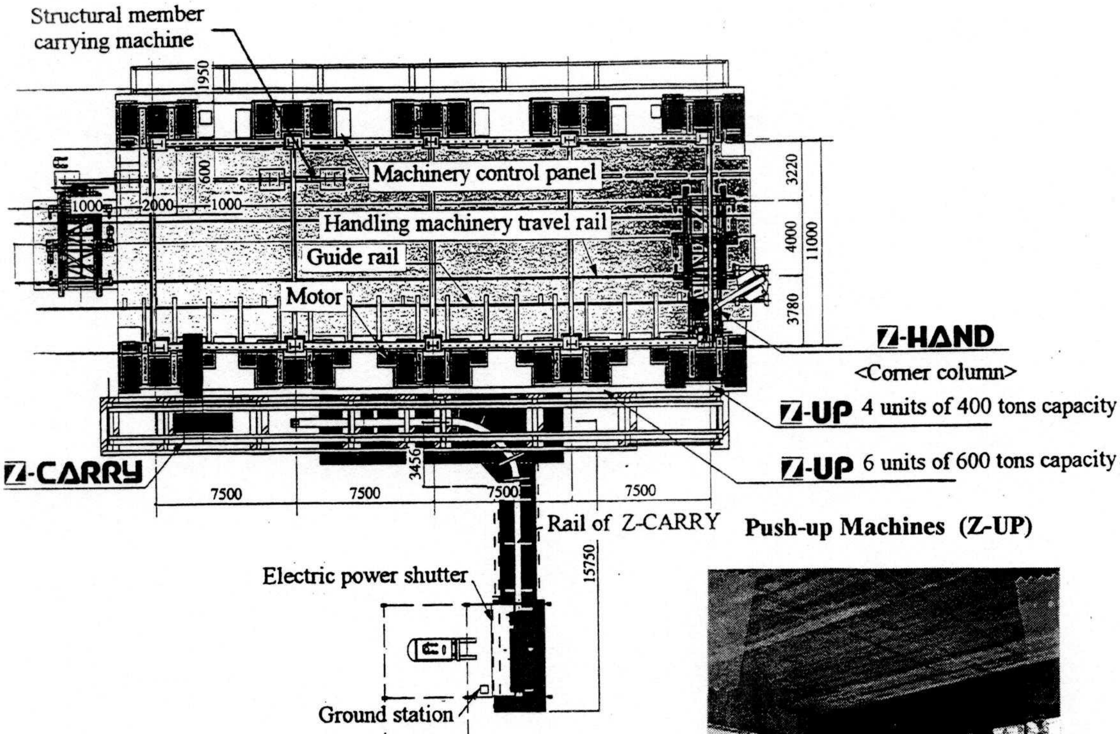
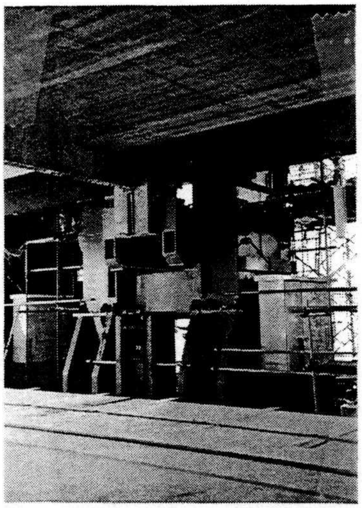
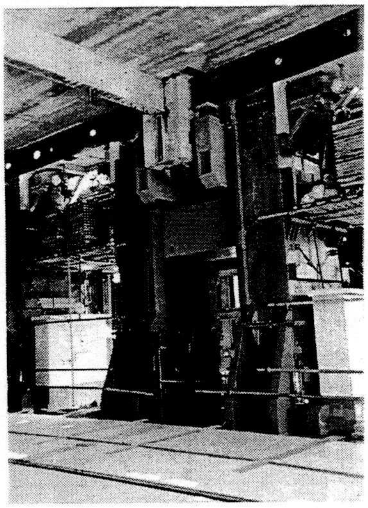


Fig.1: Construction Process of AMURAD System (EX. 9F, SRC)

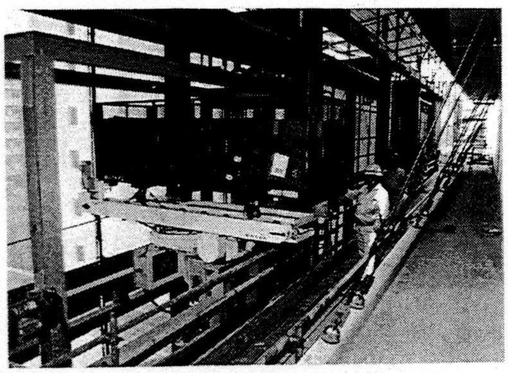


Push-up Machines (Z-UP)





Material Handling Machine (Z-CARRY)



Structural Member Handling Machine (Z-HAND)

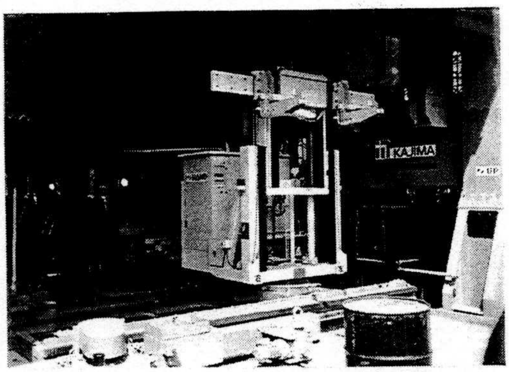


Fig.2: Installation Location of Machinery

floor which, at that time, were located on the ground and lower levels. By way of reference, during the construction work processes in this project, on the then first and second floors, structural member work was carried out, and on the third floor, external works and utility work were performed. The fourth floor was for utility and interior work, and on the fifth floor, final finishing work was implemented. Construction work was completed on October 20, 1996, and the total work period required 10 months.

3.Implementation of information integration

1) System composition

Another core aspect of the AMURAD system is the computerized integration and management of construction production information under the basic concept of CIC (Computer Integrated Construction). Fig.3 shows the overall composition of the system.

In this system, certain elements including design CAD (Computer aided design) such as information on structural materials and equipment /finishing parts, and basic information on the contractors involved and work details are all input into Project Data Base (PDB). The dedicated data base was developed specially for the AMURAD System to effect integrated management of the various information involved. Based on this information, the requisite plans, such as work control, materials control, and transportation flow of materials, all coordinated with daily work process plans, are automatically generated and implemented. Information collected on site such as work completed and material transportation flow are input into the data base and managed on an integrated basis as completed work data.

2) System operation

Fig.3 shows the flow of information among the various systems. This paper places particular emphasis on the construction work management stage (site operations) as follows. First, the site supervisor confirms the latest work scheduling information (daily unit) with the work scheduling management system in line with the daily progress, and transmits this to the PDB. Based on the work scheduling data received, the PDB effects multiple processing of the recorded data, and automatically generates transportation instruction data and work instruction data. This data is passed to the distribution management system and the work preparation

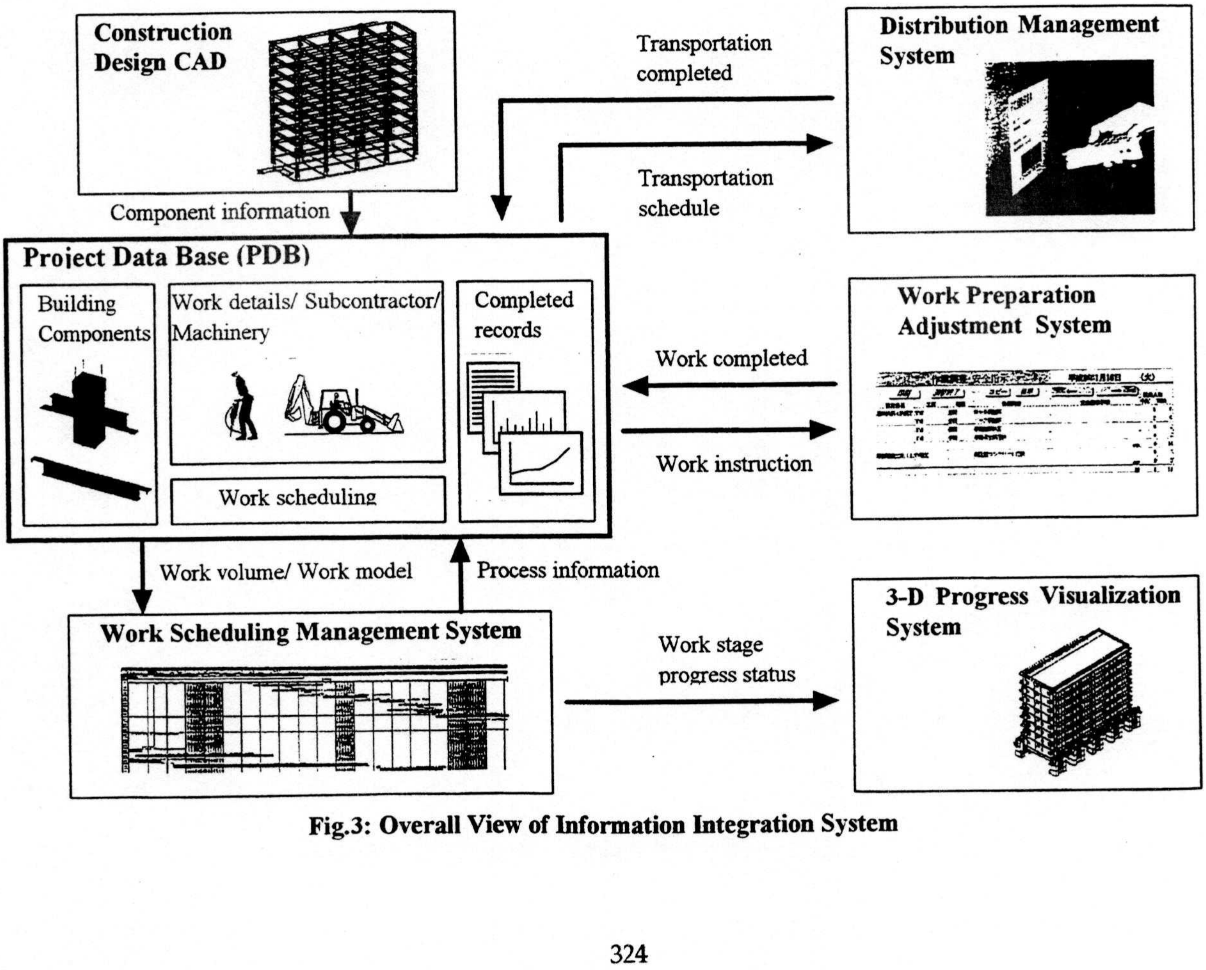


Fig.3: Overall View of Information Integration System

adjustment system. The data is employed for issuing transportation instructions and work instructions to the workers. The information on actually completed operations relating to transportation and work, collected by both systems, is sent back to the PDB and managed on an integrated basis.

Through the application of this system, adjustment of information relating to changes which occur in stage management is effected, and accurate information in line with the actual status of each system is provided. Consequently, this prevents omissions in terms of preparations and reduces or eliminates the work of complex input operations. This has simplified the analysis and evaluation of the collected data on work completed, and facilitates the utilization of this data as an asset for the next work project.

4. Details of element technology and results of application

1) Push-up machines

(1) Details of the machine.

The push-up machine has a mechanism in which the left and right frames act as guides and the arm is raised using power-driven screws. The tip of the arm supports the column end bracket section of the structure. The power driven screw system was chosen because it gives good control properties, is stable during decent, and has a self-locking mechanism, etc.

(2) Control system.

In this project, a total of 10 jacks were used. These included 6 units of 600 tons capacity and 4 units of 400 tons capacity. The height of the columns to be supported and the support load were measured, and this was fed back to the speed control of each jack, and so control management was effected. Through this, during the push-up operation, the difference in height of adjacent columns was controlled to within 3 mm, the maximum displacement of the ten columns was controlled to within 10 mm, and load distribution was subjected to uniform alignment control. In particular, with reference to the measurement of height, a digital linear scale was used making possible adjustment of 0.1 mm increments.

(3) Work sequence.

In the push-up operation, first the weight of the building was transferred to the column bearing bases, and the push-up machine was in an unloaded state. Next, the arm was extended outside the building and lowered down one floor while avoiding the girders. Then, the arm was retracted, and after leveling adjustment, it reassumed the load of the building and raised the building up to the required height. (One floor up).

The stroke length for one floor was 3.2 meters, and it ascended at a speed of 15 mm/min. and required 3.5 hours to perform the lift.

(4) Accuracy control.

In this work project, in the final stage (pushing up the second floor) the 600-ton jacks bore a weight of about 350 tons and the 400-ton jacks bore a weight of 230 tons. The total weight of the building was about 3,000 tons. This represented a push-up load of about 60% of the jacking capacity of these machines. Fig.4 shows actual data on push up accuracy control. From this figure, we can see that the maximum difference in height among

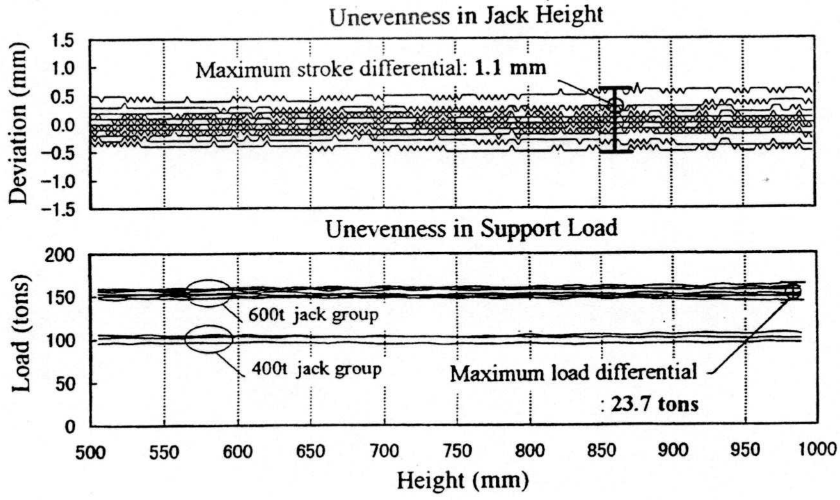


Fig.4: Results of Push-up System

the ten machines was 1.1 mm and the maximum difference in load was 23.7 tons. Thus, extremely stable alignment control adjustment was achieved.

2) Installing the structural members

(1) Detailed installation sequence.

For the installation of the various structural members such as PCa columns, steelwork girders, PCa girders, and PCa floor slabs, we used a structural member installation handling machine and two structural member carrying machines. The installation sequence was as follows. After push-up operation, each PCa column was suspended below the columns of the next floor up, steel girders were temporarily attached between the column brackets, and the stringer direction was determined. Next, the span direction PCa girder was attached to the suspended material secured below the girders of the upper floor. Forms were attached to the on-site concrete placement section. The PCa floor slabs were laid in the space between the PCa girders on the 40 mm flange. Consequently, when laying the slabs, each floor slab was inclined at an angle of 15 degrees and raised. When it passed the PCa girder, the slab was brought to a horizontally level and put in place. (Photos 1 and 2 show the installed steelwork girders and the PCa floor slab).

(2) Installation cycle time.

Fig.5 shows the amount of time required for the installation of each structural member, indicated by construction floor level. For the first cycle (construction of the 8th floor) each structural member installation operation required a considerable amount of time

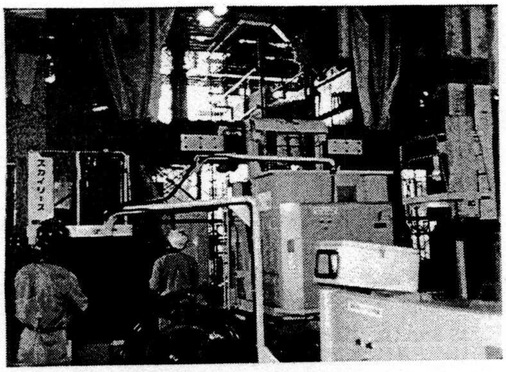


Photo 1: Steelwork Girder Installation

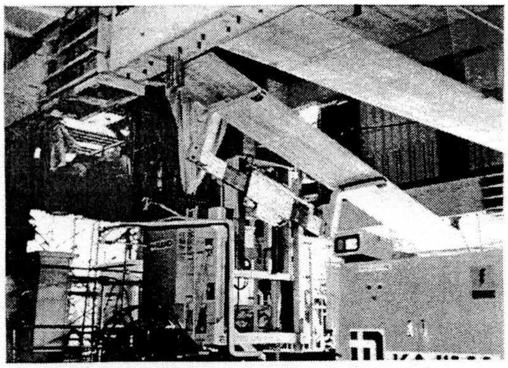


Photo 2: PCa Floor Slab Installation

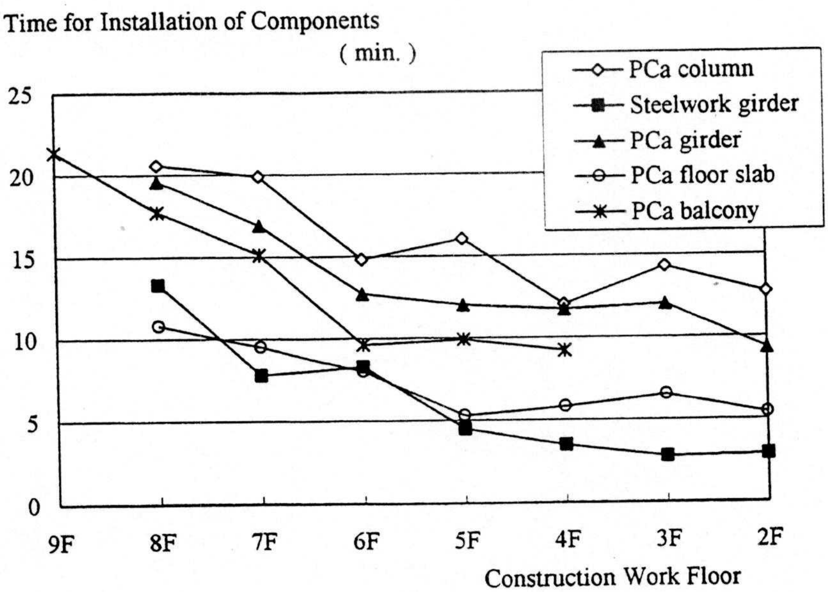


Fig.5: Time Required for Installation of Various Components

because the workers were not yet accustomed to the operation of the various machinery used and the procedure for installation. However, as the cycles progressed, the workers became markedly more proficient, and from the third cycle onwards (construction of the sixth floor), installation was effected within a very stable cycle time.

As a result, during the construction work on the fourth floor (fifth cycle), the time required for the installation of each structural member (one piece) was as follows: PCa columns; 12 minutes, steelwork girders; 3.5 minutes, PCa girders; 12 minutes, PCa floor slabs; 6 minutes, balcony PCa slabs; 10 minutes. These results are all an improvement on the times projected before the start of work.

5. Evaluation of the system

1) Labor saving and reduced generation of industrial waste

Fig.6 shows a comparison of the construction production rate between the construction the same type of condominium complex using conventional construction methods and this project in the Nagoya area. In this project, through the utilization of the AMURAD System, it was possible to achieve an overall reduction in construction workers of about 22%. Especially, regarding structural members and the temporary structure, a reduction of about 40% in workers over conventional methods was achieved.

Moreover, in this project, compared to conventional construction systems, the volume of industrial waste was reduced by 50%, and concrete chipping work was reduced by about one third. Moreover, it was confirmed that this is an environmentally-friendly construction system.

2) Shortening of the construction period

In this project, it was demonstrated that a saving of about 2 months, or 20%, was achieved in terms of the work period. In the case of this building, construction of the balconies and passageways of the second and third floors and the finishing work on the third floor and below were carried out after removal of the machinery and equipment. If it were possible to shorten the time required for the disassembly of machinery and

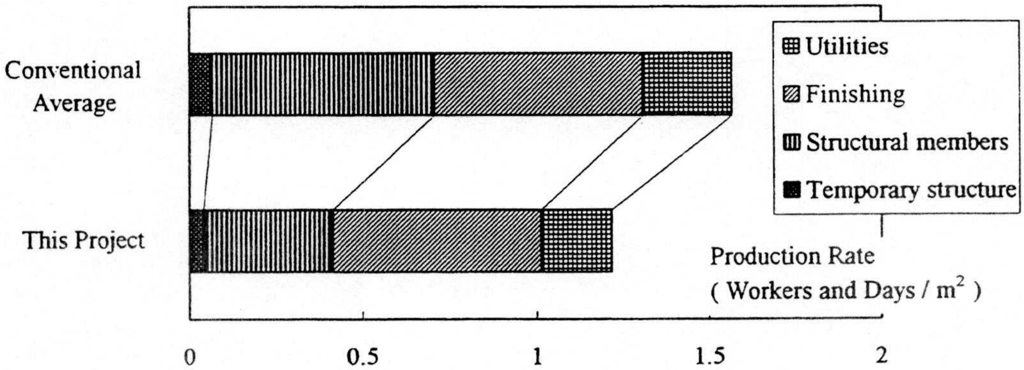


Fig.6: Construction Work Production Rate Comparison

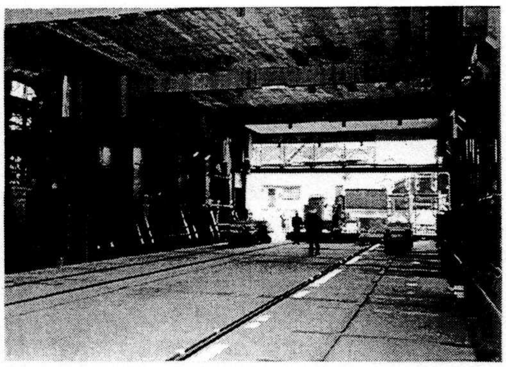


Photo 3: Interior of Construction Factory

Photo 4: Exterior of Building During Construction

equipment and simultaneously implement the finishing work on the third floor and below at the same time, it would be possible to further shorten the construction work period.

3) Improvement of the site environment

Photo 3 shows the interior of the construction factory, and Photo 4 shows the exterior of the building during construction work.

The top floor permanent roof construction work was carried out first. Thus, the interior of the construction work factory became an all-weather work environment, and the work stages were stabilized. At the same time, a pleasant site working environment was created.

Moreover, it was not necessary to build up the scaffolding progressively higher than the building as is the case in conventional construction systems. In addition, it was almost completely unnecessary for the workers to go higher than the fifth floor level above ground, and it was not necessary to haul loads up to high elevations. As a result, the danger of workers falling and of flying objects was greatly reduced, and a safe work environment was maintained which was very popular with the workers. Consequently, it was possible to complete this project with no accidents and no incidents.

Thus, in terms of the appearance of the work site, completely in contrast to conventional construction systems where a high scaffolding structure tends to dominate the area, in this project the completed building progressively emerged and grew upwards giving a pleasant external appearance to the building. In addition, the dust, noise and vibration generated on site were all reduced, and this ensured a major improvement in the construction work environment in terms of the effect it had on the surrounding area.

6. Conclusions

The newly developed AMURAD system was applied to an actual construction project. Here, we will briefly summarize the results achieved.

(1) The implementation of a fixed work cycle on the same floor within the construction factory protected by an all-weather system contributed to improved productivity and safety and an improved work environment.

(2) A major improvement in the work environment vis-a-vis the surrounding area was achieved.

(3) Simultaneous parallel implementation of the numerous work operations resulted in a shortening of the work period.

And, utilizing the experience gained from this project, we intend to further enhance and improve the AMURAD System for application to new projects.

Finally, we would like to express our gratitude to all those concerned in the development and implementation of the AMURAD System for their cooperation and support.

Reference works:

[1] "The AMURAD Automatic Construction System Utilizing The Push-Up Method" by Kansuke Honma and Tomofumi Sekiguchi et al. from "Architectural Product-Engineering" November 1996 edition.