Automation and Robotics in Construction XII
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DEVELOPMENT OF A NEW BUILDING CONSTRUCTION METHOD, THE ARROW-UP SYSTEM FOR COMPLETING THE WHOLE BUILDING AT THE SAFE GROUND LEVEL

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Abstract

The Arrow-up System (AUS) is a new building construction method developed to complete a whole building, from structural work to finishing work, all at the ground storey level. First, principal building production plants will be provided at the ground storey level on its construction site. The structural work and exterior finishing work of the uppermost storey will then be carried out. Upon its completion, it will be thrust up all the way to the top storey level. Repetition of this procedure will continue until all other lower storeys are completed.

AUS consists primarily of a stage jack unit. In system production control, the control station provided in a site office, performs all control functions such as operating the system, ensuring safety, balancing the lines, recording work progress, and issuing the necessary commands. The introduction of AUS dispenses with work which otherwise would have to be done in elevated locations ensuring a good working environment and allowing for work to be carried out under any kind of adverse weather. AUS can also stabilize the quality of work to be performed, without affecting electric wave bands.

1. INTRODUCTION

The Arrow-up System is a new building production system which can be located at the building ground level so that the whole building can be constructed storey by storey, starting from the top level and continuing with lower storeys, using purpose-made jacks.

The aim of this development is to complete all types of work, from the erection of the structural steel members to roofing and exterior wall cladding, including finishing work, all at the ground level. Therefore all hazardous work at elevated places can be avoided in order to ensure improved productivity and safety and shorten construction time. In this paper, the results of the Arrow-up System's first application to the construction of a vertically rotational parking tower are described, and the effects of the application and the system's future development are discussed.

2. DEVELOPMENT HISTORY OF THE ARROW-UP SYSTEM

2.1 Building Overview

Use: Vertically rotational type parking tower (capacity: 32 middle-sized cars)

Construction: Steel frame

Scale: Height: 30.96m, size: 5.5m x 6.45m

Exterior cladding: Roof: waterproof sheeting

Exterior wall: sandwich panel t = 31mm

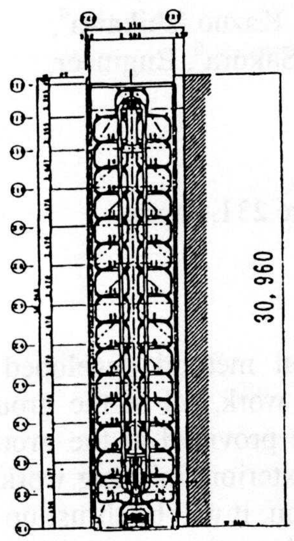


Figure 1. Section

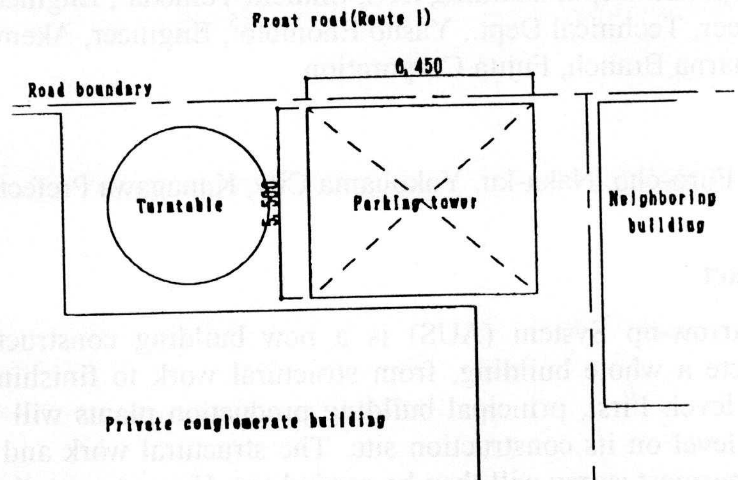


Figure 2. Plot plan

2.2 Evolution of System Development

Conventionally, the construction of a parking tower would be carried out in the following order:

(1) Erect scaffolding, and then steel members, by using large, heavy construction equipment.

(2) Erect exterior wall panels storey by storey, starting from the from the lowest storey.

(3) Install the drive of the parking system.

(4) Perform roofing work.

(5) Install all other parking equipment and carry out painting and fireproofing work.

The building site would be very cramped with little space in which to manoeuvre the Arrow-up System and the parking tower in question had to be located adjoining National Route 1, a trunk road which is constantly jammed with traffic. This means that we would be unable to use large hoisting equipment, and had difficulties in the erection of scaffolding. Therefore ensuring safety during the process of construction was very difficult. To effectively address these drawbacks, we developed a building system called the "Arrow-up System" founded on the basic concept of enabling every kind of work to be carried out on the ground level.

3. SYSTEM OVERVIEW

The basic concept of the Arrow-up System is such that, as illustrated in Figure 3, steel members and exterior walls are erected to first create the top storey which is then thrusted up by a jack unit to its designed position and level. Thereafter, the same procedure is repeated to construct all other lower storeys one by one until the whole building is completed. The system designation "Arrow-up System" has stemmed from the state in which every pre-erected building story climbs up like an arrow shooting to the sky from the ground. With the conventional procedure, buildings were erected from the lowest storey, on top of which extension steel members and exterior walls were then installed. The Arrow-up System does not basically need scaffolding and any other erection aiding tools and systems, but needs only small construction equipment for the erection of the steel members.

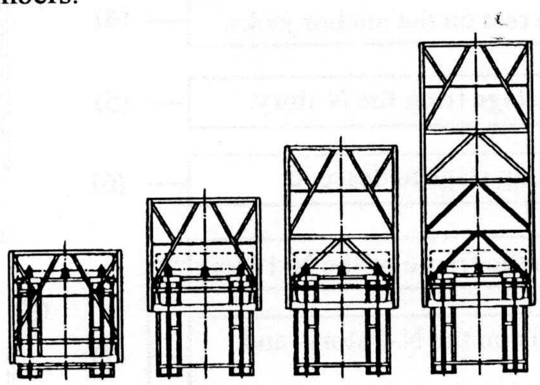


Figure 3. Conceptual Arrow-up System plan.

3.1 Jacking-up Unit

The Arrow-up System is supported with a stage jack unit consisting of worm jacks, anchor jacks and support jacks, all of which are computer-controlled to push up each storey erected in advance. Jacking up was carried out in a way in which the steel members were secured to a travelling stage climbing up and down the outside of the stage jack unit, and the worm gears were then operated to thrust up the storey, together with the travelling stage.

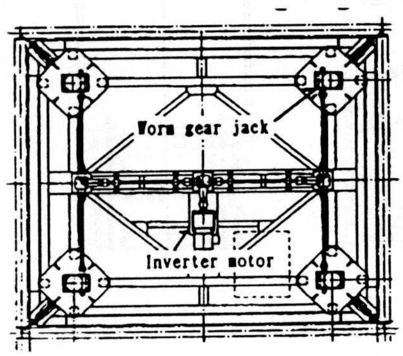


Figure 4. Plan view of the stage jack unit.

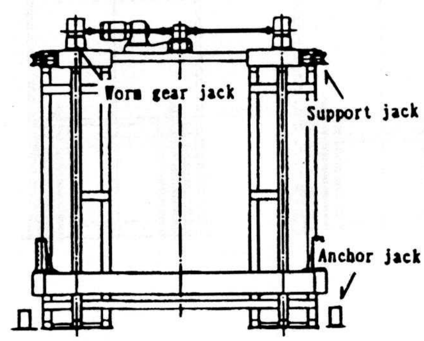


Figure 5. Elevation of the stage jack unit.

3.2 Erection Steps

Figure 6 shows the flow of the erection procedure, and Figure 7 illustrates the work steps (1) to (7).

(1)
- Install the stage jack unit
- Erect the uppermost storey(N) on the travelling stage

(2) Jack up the travelling stage so as to push up the erected story.

(3) Assemble the frame of the N-1 story, and connect it to the N story.

(4) Allow the entire load to rest on the anchor jacks.

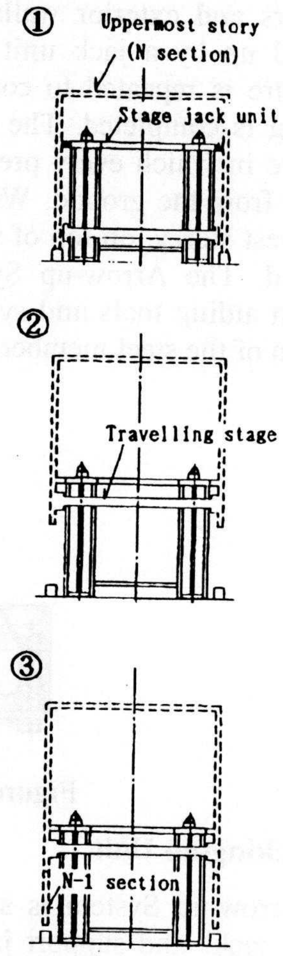
(5) Detach the travelling stage from the N story.

(6) Operate the travelling stage to descend.

(7)
- Fix the travelling stage to the frame of the N-1 story
- Install exterior wall panels on the N-1 story, and finish them.
- Operate the travelling stage ordering it to ascend so as to thrust up the N-1 story.

Assemble the frame of the N-2 story, and connect it to the N-1 story.

Figure 6. Flow of the jacking up steps.



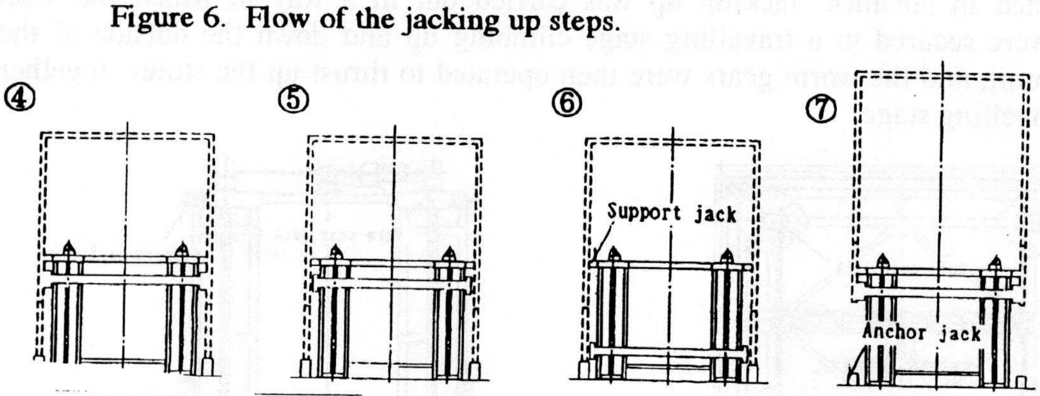


Figure 7. Schematic erection steps.

3.3 Features

The features of the Arrow-up System are described below.

(1) As almost all types of work can be done at the ground level, performing of the building tasks at elevated places can be avoided, also the danger caused by the objects being dropped down from great heights on building site can be reduced.

(2) Uniform type of activities can be employed together with the type of material transported for the construction of each story:

(3) Similar to the manufacturing industry, materials flow on a stationary production line, making it easier to introduce the mechanized production.

(4) The ability of doing everything at the ground level produces a building with a uniform quality.

(5) The ability to complete the roof first enables the performance of all other building activities even in adverse weather.

4. CONSTRUCTION RESULTS

4.1 Construction Summary

(l) Gross weight to be jacked up is as follows:

Steel members (divided into 11 sections)	:46 tons
Exterior cladding(sandwich panels)	:20 tons
Parking equipment (the drive section alone)	: 8 tons
Travelling stage	: 8 tons

(2) Jacking up height

The building was approximately 31 meters high. Steel members were divided into eleven sections, each section being 2.7 meters high which was less than the worm jack's stroke length of 3 meters.

(3) Jacking up speed

Each section was jacked up at the speed of 90mm per minute, for the total of 30 minutes until one section can be set in place.

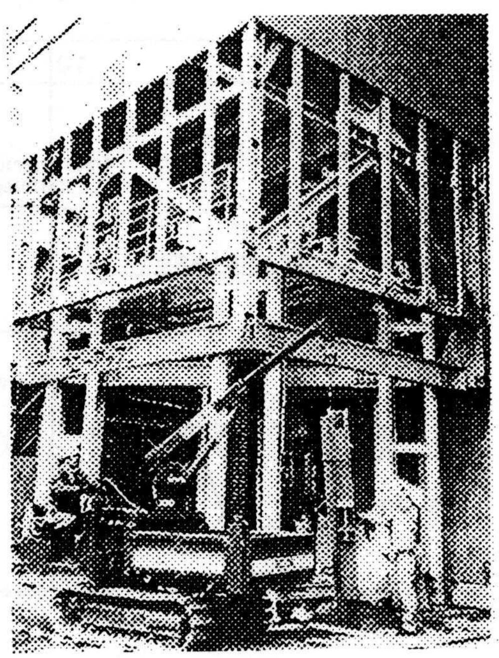


Photo 1. A steel column under erection.

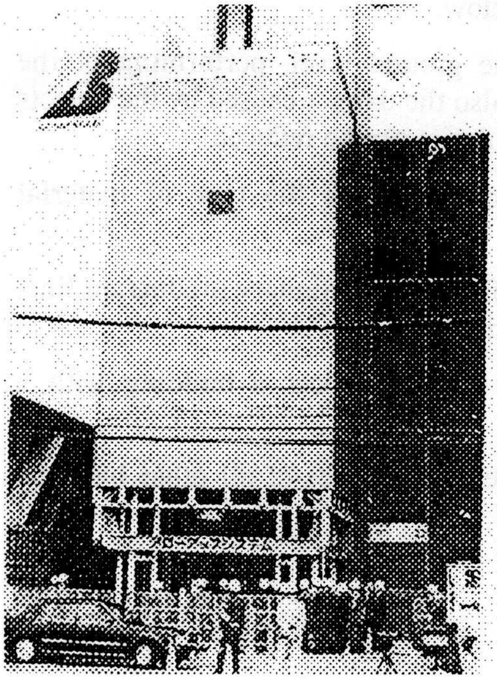


Photo 2. The N-6 section is being jacked up.

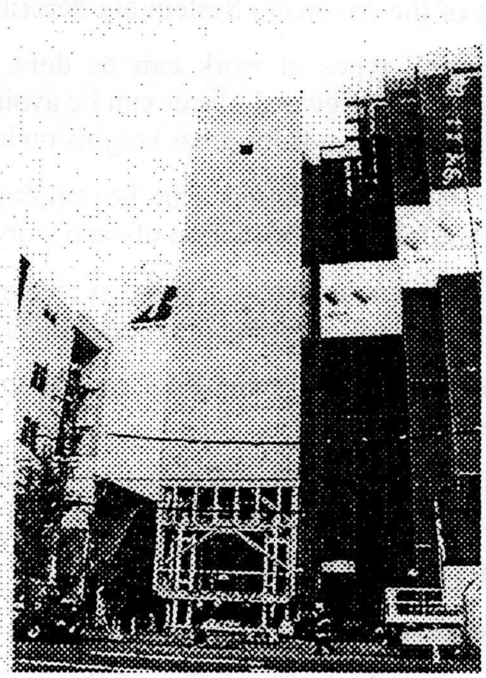
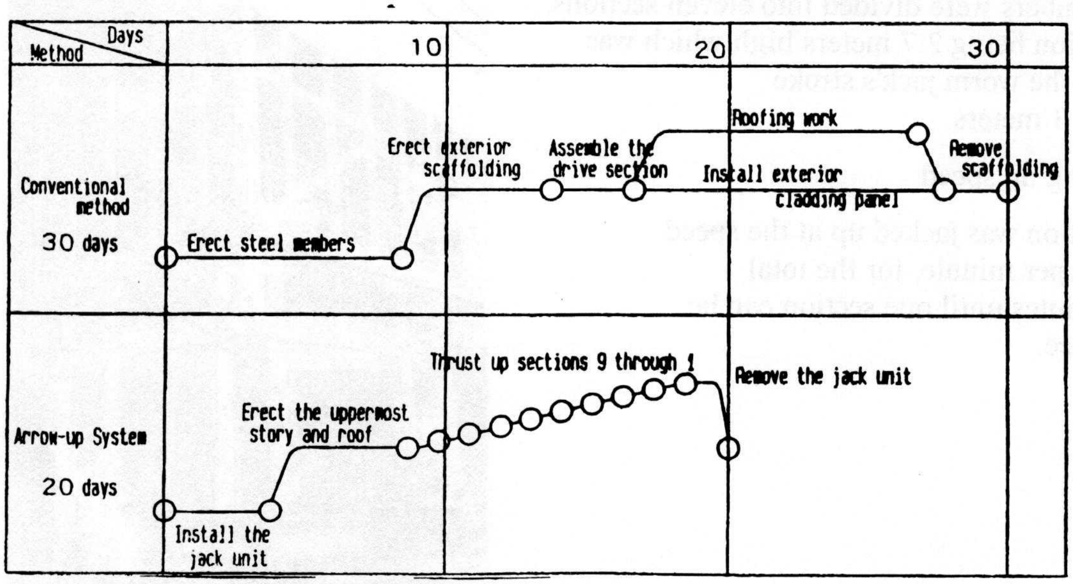


Photo 3. The last section (the N-2 section) is being jacked up.

4.2. Construction Schedule

As compared to the conventional construction method, the period of time needed for the completion of the whole building from the commencement of steel erection, to the completion of exterior cladding, was able to be shortened by ten days as shown below.

Table 1. Comparison of construction schedules



4.3. Accuracy Control

Each of the four worm jacks was of the screw composition and all of them were perfectly tuned. Thus, since the vertical accuracy of the building would depend on the fabricated accuracy of steel members for each section, the fabrication tolerance of lmm was allowed for each of the columns. Also, for the measurement of lateral distortion of steel members under erection, we used a laser type verticality measuring instrument so that the measured figures can be displayed at real time on the CRT of a PC. The maximum value which was actually measured was 15mm. This distortion was accommodated during the erection of the lowest section. The load that was applied onto each of the jacks could be displayed on the monitor incorporated in the control panel of the jack. This also enabled the control of the eccentric load.

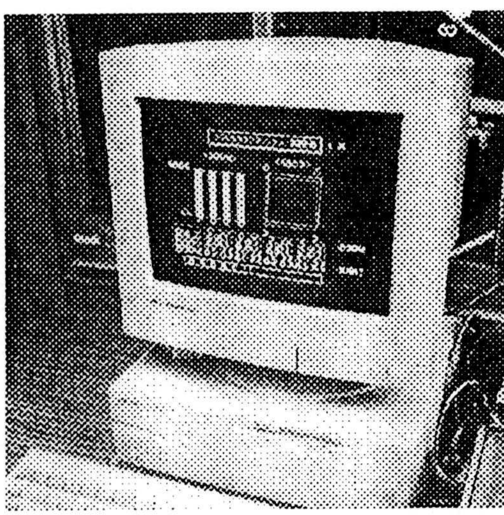


Photo 4. A picture showing a measured level displacement.

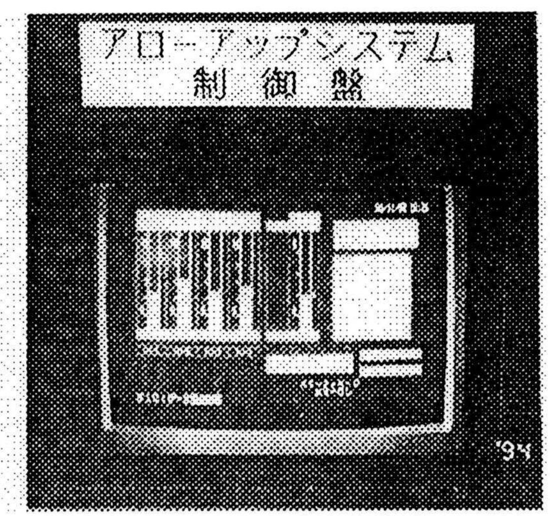


Photo 5. A picture on the monitor showing the stage jack unit

4.4. Safety Control

The basic design concept required, that the stage jack unit itself was equipped with such strength for the unit to be able to withstand a wind velocity of 30 meters and also a seismic force of up to 0.15 in the coefficient of storey-shearing force. Additionally, the inside of the unit is braced with wires to ensure safety.

As a whole, the Arrow-up System gave the workers and the operators an assurance that it can be operated safely, as it needs neither exterior scaffolding nor any type of work to lift materials of any kind.

5. CONCLUSIONS

As compared with the conventional construction method, we were able to achieve better results in the areas of the construction schedule, quality and safety. Also, it was important that as a first experimental project, the parking tower could be completed at almost the same cost as with the conventional method. In the future, we will continue to introduce further improvements and a more rational Arrow-up System, through the following steps: 1) devising simple auxiliary components to enable the Arrow-up System to be fit to any size of building, 2) training workers to improve their versatility, in order for them to perform tasks more efficiently, and 3) developing an improving transportation system which is capable of hauling up fabricated steel members and exterior cladding materials more easily.