Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)

Totally Mechanized Construction System for High-Rise Buildings (T-UP System)

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Abstract

To totally mechanize construction work in building production, particularly through the introduction of robots, construction methods that can be carried out by machines must be developed. In developing new construction methods, the characteristics of construction machinery must be carefully considered, and new machines and materials must be developed. Mechanized construction is most effective in the construction of building superstructures built of large and heavy materials.

To maximize the efficiency of mechanized construction, a continuous cycle of transportation and assembly with each type of member must be used to build superstructures. Through repetitions of this cycle, it should be possible to build superstructures quickly and without interruption. To develop mechanized construction systems, the machine systems and material systems to be incorporated must be examined, and the configurations of thebuilding components must be systematized and classified. This report describes the development of T-UP, a new method for robotization of the construction of building superstructures built of large and heavy materials. It also describes some examples of how the T-UP System has been used in superstructure construction.

1. CHARACTERISTICS OF CONSTRUCTION PRODUCTION AND THE COMPONENTS OF CONSTRUCTION METHODS

To implement mechanized construction systems, various components must be classified and then incorporated into systems appropriate for them. Both the classification of the components and their incorporation into systems is based on the characteristics of construction production, which are different from those of other types of industries. The three characteristics of construction production that are particularly relevant to the development of mechanized construction systems are as follows:

(i) Construction materials are diverse, and are usually heavy, thick, long, and large.
(ii) Construction products, (completed buildings) are usually not movable.
(iii) Construction products, such as parts of buildings and completed buildings, usually occupy a lot of space.

Consequences of (i):

- Machinery for transporting and processing construction materials is large and exceptionally heavy, and requires structures that can stably support it.

Consequences of (ii):

- Machinery must be movable so proper working distances can be maintained as the shape and size of a building change with the advancement of construction.

Consequences of (iii):

- Machinery must work over large areas, thus support structures must be movable and supported by the ground or a manipulator base fixed to the ground.

Figure 1 shows a schematic diagram of the components of construction methods used in the application of mechanization to all construction work. A model outlining, with symbols, the components of construction methods is shown on the right side of Fig. 1. The three machinery systems for totally mechanizing construction are outlined below. Construction materials are usually heavy, thick, long, and large, and require large machinery; therefore, because of the time and expense involved, for temporary work it is inappropriate to individually fabricate and use these systems and to remove them after construction is completed. To deal with these problems, we decided to use the following procedures for each of these systems.

- Support for the manipulator base (S)

A floor is built six or seven floors above the lower working space of the superstructure. This floor is used as a support for the manipulator base.

- Base for manipulator (B)

The floor that will be the top floor, or quasi-top floor, when the building is completed, is used as the manipulator base.

- Manipulator (M)

Existing machines are used wherever possible. When new machines need to be developed, they are designed as modules so they can be used for other jobs and can be easily disassembled and transported.

Our new construction method is based on the S, B, and M systems and we have named it the T-UP System. The basic concept of this system is to develop a totally mechanized construction system.

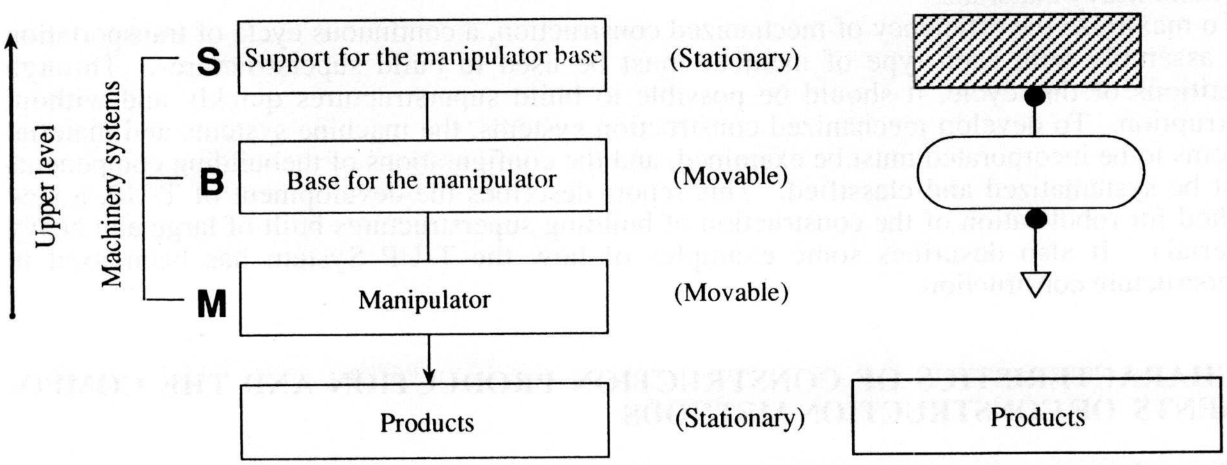

Figure 1. Classification of Components for Mechanized Construction Systems and Symbol Model

2. VARIATIONS OF THE T-UP SYSTEM

When various construction components are applied to existing buildings, variations of the T-UP System are possible. Figure 2 shows some example variations.

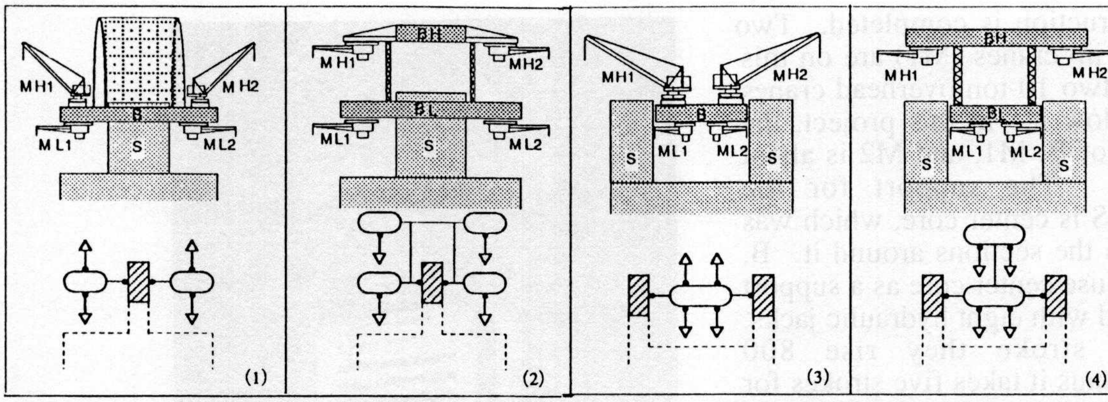

Figure 2. Variations of the T-UP System

3. APPLICATION OF THE T-UP SYSTEM

Of the combinations of components related to the mechanized construction described above, the form shown in No. 1 in Figure 3 was applied to the construction project outlined in Table 1.

Table 1. Construction Outline

Project Name	Mitsubishi Heavy Industries Yokohama Building, Phase 1 Project
Location	3-3-1 Minatomirai, Nishi-ku, Yokohama, Japan
Building Area	6,178 m^2
Total Floor Area	110,918 m^2
Floors	Two below ground, 33 above ground, and a tower
Structural system	Superstructure: Steel (S), substructure: Steel-reinforced concrete (SRC)
Height	145.3 m
Use	Offices, cultural spaces, retail spaces
Contractors	Taisei Corporation and 14 joint venture companies

3.1 Details of the Application of the T-UP SYSTEM

With T-Up System, the top floor is constructed on the ground and used as the support for the manipulator base. As the superstructure is assembled, this support is raised with machines such as overhead cranes and jib cranes. The overhead cranes are installed below the support and the jib cranes are installed above it. The key concept of the T-UP System is to use the superstructure as a production apparatus to the fullest possible extent.. To realize this, the top floor (hat truss) is used as a production platform. The platform weighs about 2,000 tons and can be raised automatically by remote control from the central control room; it can kept within 5 mm difference of level as it is raised. By controlling the platform in this way, the superstructure construction cycle can quickly advance. It looks as if the machining center is in the FA factory.

A construction project using the T-UP System is presently underway 30 kilometers west of Tokyo in the city of Yokohama. The project is scheduled for completion in March 1994. Photo 1 shows the overview of the project. Photo 2 shows the arrangement of the cranes on production platform. In Photo 2, B is the base for the manipulator, and will be the top floor when construction is completed. Two 150-ton • m jib cranes (M1) are on this support and two 10-ton overhead cranes (M2) are below it. In this project, the total weight of B, M1, and M2 is about 1,900 tons. The support for the manipulator S is center core, which was built prior to the sections around it. B, M1, and M2 use center core as a support and are raised with eight hydraulic jacks. With each stroke they rise 800 millimeters, thus it takes five strokes for them to rise 4 meters, which is the height of one floor. The five strokes take about 110 minutes.

Procedures of the T-UP System are outlined below. (See Fig. 3.)

(1) The steel structure of the core is erected up to the 7th floor. (Phase 1)

(2) Guide columns are installed at eight places around the core. They are used to jack up the production platform and contain 300-ton hydraulic jacks for this purpose.

(3) The top floor of the building, which functions as a production platform, is assembled on the ground. (Phase 2)

(4) Two jib cranes, which are used to assemble the core, are installed on the production platform. An all-weather roof over the area where the core is to be assembled is erected.

(5) The production platform is slightly raised so that the two over-head cranes for assembling outer sections can be installed. (Phase 3)

(6) Machinery installed to this point is put through final trial runs.

(7) Assembly of the core and outer sections is started using the cranes above and below the production platform. When assembly of a floor is completed, the construction cycle for jacking up to the next floor begins. (Phase 4)

(8) When the production platform reaches the height of the top floor, the temporary facilities installed on it, such as the all-weather roof, are removed. The overhead cranes are also removed. (Phase 5)

Photo 1 Implementation of the T-UP System

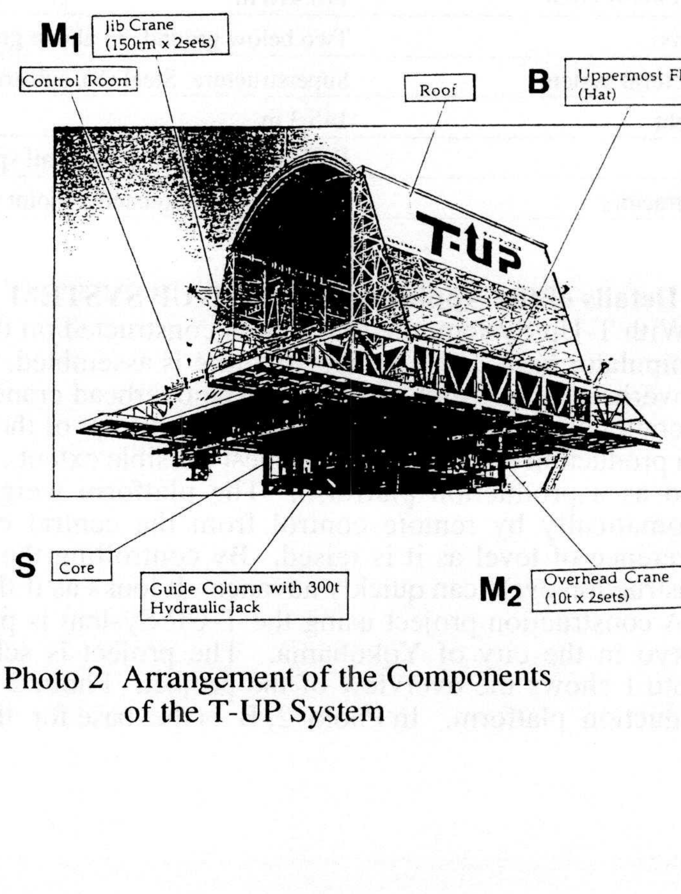

Photo 2 Arrangement of the Components of the T-UP System

(9) The production platform is lowered and becomes the top of the building.
(10) After construction of the tower is completed, the jib cranes are disassembled and removed. (Phase 6)

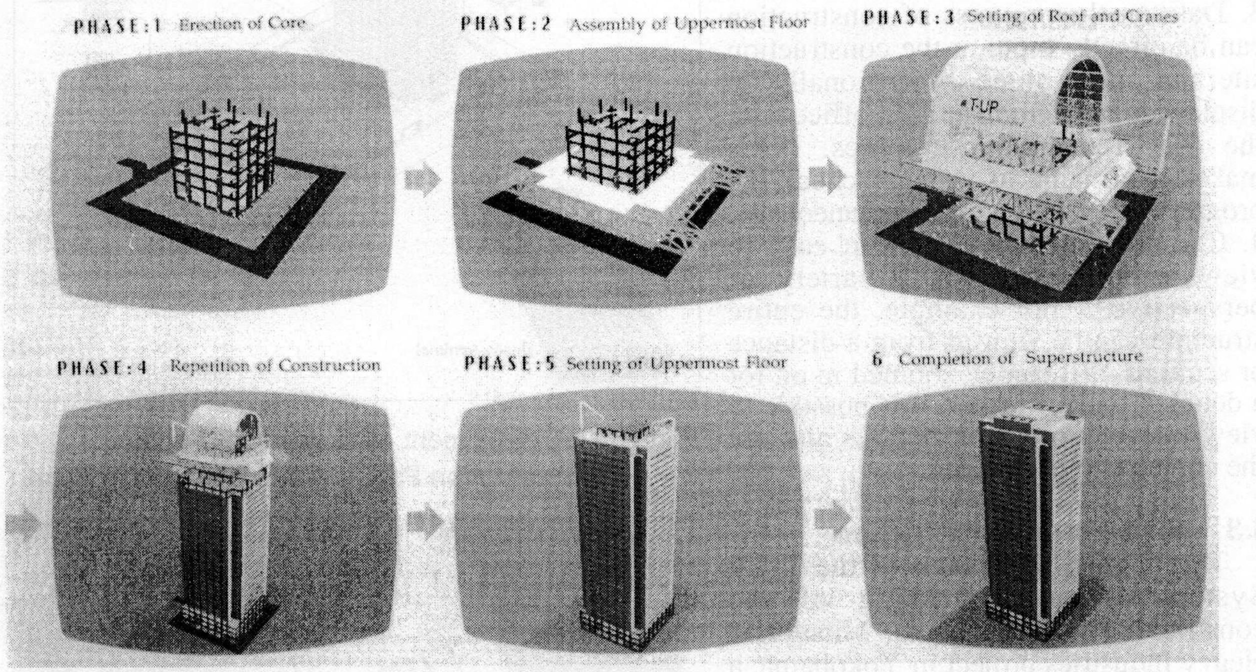

Figure 3. Construction Procedures of the T-UP System

3.2 Construction Progress Controlling System for Steel Structure Erection

A lot of support technology is essential for the T-UP System. One of the technologies this report describes is the construction progress controlling system in the construction of steel structures. This system uses computer graphics to display information three-dimensionally on CRT screens at the site office. Information displayed includes manufacturing data sent by fax to the office from each steel member manufacturer and data on assembly conditions which is input directly at the production site. With the system, progress in the construction of steel structures can be managed not only through characters and words, but also through images. This makes progress easier to understand and results in fewer errors. Construction data is input by foremen at the site into handheld computers and immediately transmitted to the office via a communications network.

Figure 4 shows the arrangement of personal computers, handheld computers, and input terminals, and Figure 5 shows the outputting of computer graphics, which are color coded for each check point. Features of the system are outlined below.

1. Three-dimensional CAD data can be used for shop drawings based on design drawings. There is continuity to the data used in all phases of work from design to construction.

2. Fabrication data can be input at steel plants and output three-dimensionally on displays in the administration office with the use of computer graphics. This makes it possible to check in real time on the delivery of members that are needed.
3. Data on the progress of construction can be directly input at the construction site and output three-dimensionally on displays in the administration office with the use of computer graphics. This makes it possible to visually check the progress of construction simultaneously.
4. Computer graphics make it easy to view a building from a variety of perspectives. For example, the entire structure can be viewed from a distance or sections of it can be zoomed in on for a detailed look. Further, it is possible to view the interiors of structures and see the contents of each floor.

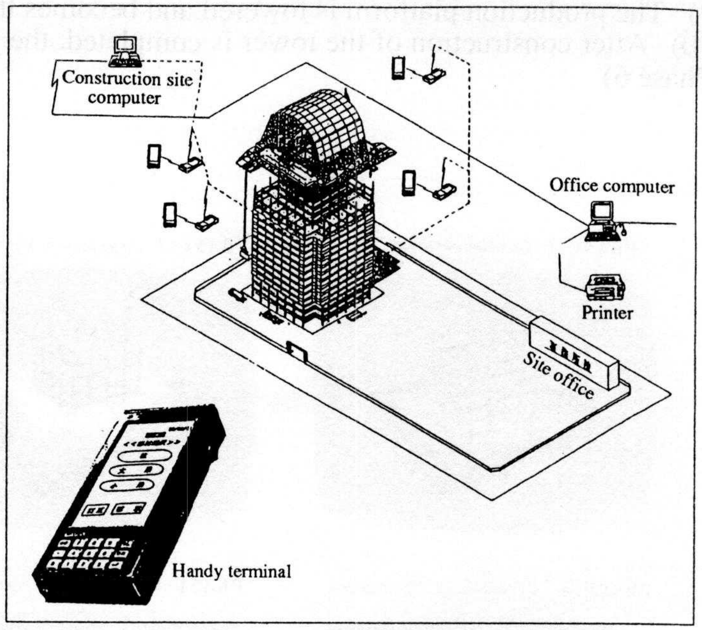

Figure 4. Arrangement of Equipment for the Production Progress Management System

3.3 High-Speed Construction

The biggest advantage of the T-UP System is the shortening of the construction period. In the Mitsubishi Heavy Industries project in Yokohama, a one floor per three days construction cycle has been established, which means that the hat truss climbs every three days.

One job on the first day of the construction cycle is to assemble the steel structure of the core with jib cranes. To do this, the crane lifts steel members outside the structure, swings around, and places the members in the interior under the roof. On the first day, each jib crane lifts about 52 pieces. Another job is to install the exterior wall precast concrete panels below the hat truss. To do this, the overhead crane lifts the precast concrete panels with the lifting bracket at the end of the hat truss and places them at specified positions in the hat truss. To position panels at right angles, the crane must move to another girder. After moving to this girder, it positions the panels at the specified positions in

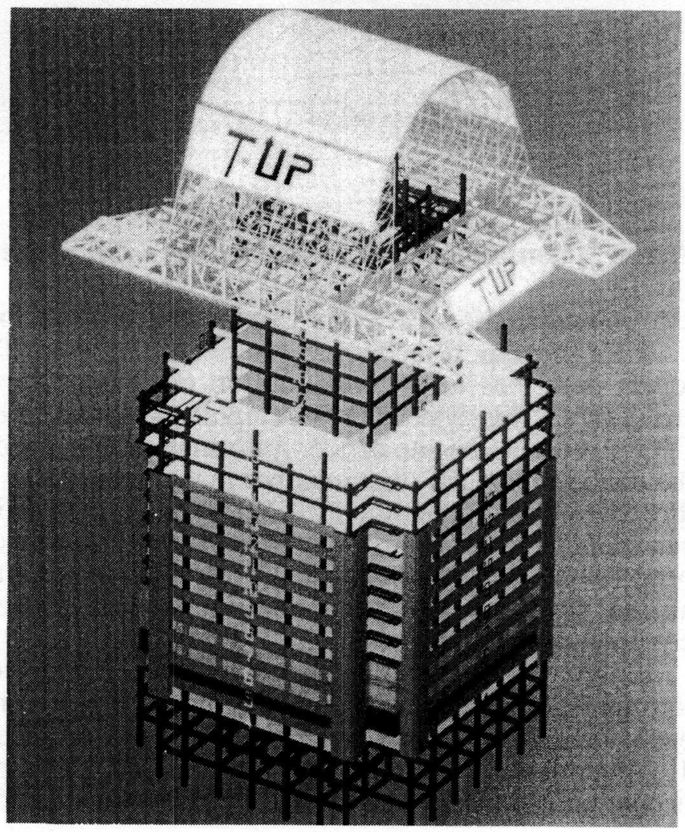

Figure 5. Computer Graphics Output on a CRT Screen

the hat truss. On the first day, each overhead crane lifts about 22 pieces. Both of these jobs are done concurrently on the first day of the construction cycle.

On the second day, steel structural members of the core are welded and the bolts are tightened. On the exterior of the building, the steel structure is erected below the hat truss. Installation of the unit floors, which are partially preassembled, also begins. On the second day, each overhead crane lifts about 44 pieces.

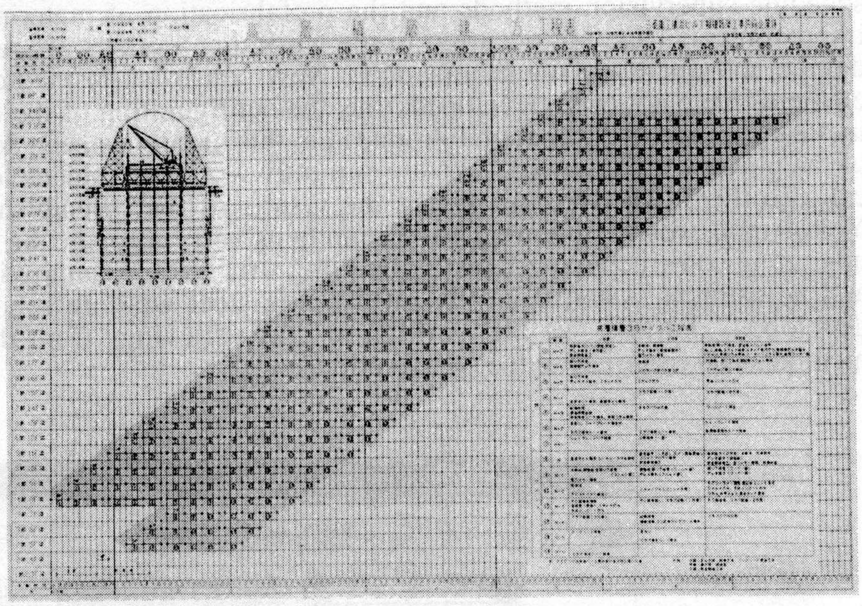

Figure 6.Tact progress chart of the Three-Day Cycle

On the third day, welding of the structural members of the core continues. Below the hat truss, steel corner members are installed. On the third day, each overhead crane lifts about 26 pieces. When welding on the core is finished, the guide columns, which are lifts, are raised one floor. Following this, the hat truss climbs along the guide columns. The hat truss thus climbs once every three days. Figure 6 shows a tact progress chart for the three-day cycle, and Figure 8 shows the contents of the work.

In this project, the steel structure was constructed at the scheduled rate of one floor every three days. This high speed was achieved not only because of mechanization, but as surveys of the workers indicate, for the following reasons as well.

- The base for the manipulator, which is the top floor, functioned as a roof, allowing construction to continue without interruption on rainy days.
- The simultaneous construction progress controlling system was a valuable tool for helping to adhere to the construction schedule.
- Learning effects were greater than expected as a result of the well-designed interface between man and machine.
- The computer-based tact schedule management plan and the rising of the 2,000-ton top floor every three days played roles similar to that of an orchestra conductor. Physically, the new system helped workers maintain a steady rhythm, and psychologically they were effective motivational devices.

This project would have been scheduled to take 30 months to complete if conventional construction methods had been used. With the T-UP System, however, it was scheduled to take 24 months. Of these 24 months, only six were needed to complete construction of the 34-storey steel structure.

4. FUTURE OF THE T-UP SYSTEM

To improve productivity in any construction project, the three key elements of production—the hands (man and machine), the means (construction methods and schedule supervision methods), and the materials (construction materials and energy sources, etc.)—must each be improved through rationalization. In building construction, good results have been achieved in schedule supervision methods and the prefabrication of materials. Unfortunately, significant improvements have not occurred in the work that workers are required to do, as well as in the degree and quality of mechanization. New construction methods which integrate these two elements have not been developed, thus the configuration of the key production elements is not in balance. The T-UP System introduced in this report has been developed to help alleviate some of the problems that remain. We are currently working on plans for the next project in which we can use the T-UP System. Using the results of the Mitsubishi Heavy Industries project in Yokohama, we are planning to comprehensively upgrade the T-UP System. We are now upgrading construction systems for building structures by improving the automatic measurement and adjustment systems and by introducing steel welding robots which are currently being developed. Further, we are working to unify drawings from the preproduct design stage of members and materials to the construction stage.

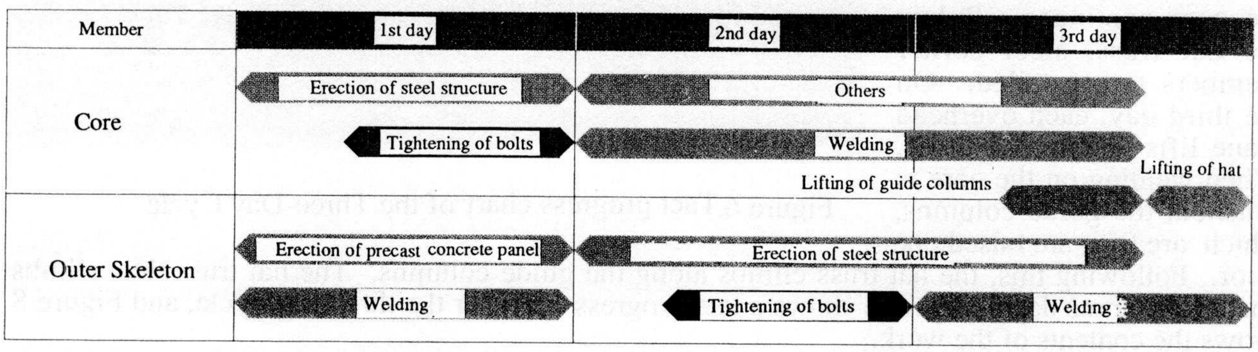

Figure 7. Progress Chart of the Three-Day Cycle

CONCLUSION

There are still many ways of improving productivity in building construction that have not been adequately explored. For example, we need to give more thought to the introduction of technologies and ideas from industries in other sectors, such manufacturing. But the most important challenge for the construction industry is to broaden its perspectives and to avoid, in the chaotic realm of the jobs that comprise construction work, devising techniques without consideration for how they can be integrated with other techniques. We strongly believe in this conclusion after thoroughly analyzing the Mitsubishi Heavy Industries project in Yokohama. As a result, one of our primary goals is to cooperate with people in the construction industry around the world to develop ways of improving production in building construction.

Finally, I would like to thank the staff of Mitsubishi Heavy Industries, which worked closely with us in the development of key technologies for the T-UP System. I would also like to extend my gratitude to the many other companies that participated in this joint venture with us.

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