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Development and Application of the SMART System

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ABSTRACT

The SMART system is an integrated automated construction system which automates a wide range of construction procedures, including the erection and welding of steel frames, laying of concrete floor planks, installation of exterior and interior wall panels, and the installation of various other units under its all weather protection covering. The system was introduced in an office building project in Nagoya, Japan, which was successfully completed in autumn, 1993. Through its application, a safe and comfortable work site, unaffected by poor weather, was realised with a reduction in labour requirement, elimination of hazardous works and a reduction in material waste.

1. INTRODUCTION

In Japan, in spite of the increased demands of construction there are growing shortages in the work force which is also ageing. Skilled craftsmen are particularly in short supply. It has been pointed out that the background to this is that construction operations involve heavy workloads with much work carried out in very adverse environments. Compensating for this shortage in the work force and reducing accidents on the work site, together with improving productivity as a means for shortening construction periods, are some of the serious tasks faced by the Japanese construction industry today.

Under such circumstances, there has been, for many years, a lot of activity in the development of robots and automation for construction work. With this basis of automation technology we seek to achieve maximum integration of the various technologies which lead to modernisation of construction i.e. technologies for industrialisation and systematisation of the various components of building and computerisation of site management.

Several major construction companies in Japan have pursued the development of systems based on similar ideas and to date there are a number of proposals. The Shimizu Manufacturing System by Advanced Robotics Technology (SMART) system of the Shimizu Corporation controls all phases of building construction from underground work and superstructure work to finishing and M&E work. It also controls various construction management tasks for the automated construction of high rise buildings.

The formulation of system started in the fall of 1990 and the core technology for the system was implemented at an actual construction site for the first time. Taking these results into consideration, the technolo gy was introduced in a full fledged manner on a project in the city

of Nagoya, in the fall of 1991. The construction by SMART has successfully completed in the fall of 1993 (Photo. 1).
In this paper, the project in Nagoya is used as an example to explain the basic concept of the system, technologies applied, construction procedures used and results for the application. Plans for future development and improvement of the system are also discussed.

2. COMPONENT TECHNOLOGIES OF SMART SYSTEM

The SMART system secures a safe and comfortable working environment, and also provides a setting for construction which is not affected by wind or rain. Furthermore, it aims for a considerable reduction in labour and management man-hour requirements, and shortening of the construction period. In addition, to respond to the prevailing social demand for protection of the global environment, a system to reduce waste materials from construction is sought.
This system is applicable for high rise office and hotel buildings which are of steel frame construction and involve large amounts of repetitive works.

2.1 Outline of the System
In the SMART System, the top floor of the building (Hat-truss) is first assembled on the ground, and an operating platform for transporting and assembling structural steel and precast concrete floor planks is formed there. While this platform is being jacked up floor by floor, lower floors are constructed in sequence, as if to add on building blocks, and the superstructure part of the building completed (Figure 1). Members such as columns, beams, floor planks, and wall panels used in the building are hauled continuously using a multiple trolley hoists, overhead cranes and a special vertical crane. A one touch joint system suited to automation and mechanisation is used to connect structural steel members and member joints are welded automatically by welding robots.
The roof and outer perimeter parts of the floor under construction are completely covered by protective sheets, and the exterior wall panels for that whole single floor are installed prior to jacking up so that the floor is unaffected by wind or rain. Safety of work is also enhanced and a comfortable working environment achieved which is unaffected by adverse weather

2.2 Lift up System
The lift up system is composed of four jacking towers which support the entire operating platform and the lifting mechanisms installed at each jacking tower. During the assembly operations of a floor, the tower bases are seated on the steel beams of the building. During lifting operation, three hydraulic cylinders in each lifting mechanism are operated and the lifting mechanisms are raised by one story height (approximately 4m) to rest on the steel beams of the storey above. Next, while supporting the operating platform on these steel beams, the hydraulic cylinders are again operated and the towers themselves are raised. When the towers have risen one story height, the bases are seated on the structural steel beams of that upper story to complete the lift up operation. Figure 2 shows the main components of the lift up system. The total weight of the entire operating platform lifted up is approximately 1,200 tons and the operating time for one storey height is 1.5 hours.

2.3 Automated Conveying System
For conveying the many kinds of members, ten overhead travelling cranes, five trolley hoists for horizontal conveying, and a special vertical lifting crane which ascends and descends by

wire drive is used instead of the large conventional tower cranes. A trolley hoist lifts up a load from the ground, rides onto the rails of the above mentioned cranes in succession and reaches its destination, all controlled by computer. Likewise, the picking up of a load and conveying this to positioning is all done automatically without manual assistance. Figure 3 shows the components of the automated conveying system. When a member is hoisted, it is conveyed in a continuous operation to reach the destination. Thus, the assembly of members can be done with less waiting time with an increase in the work per day. Photograph 2 shows a steel column which has been hoisted and, having reached its destination, is being installed into place. Photograph 3 shows the vertical lifting crane located outside of the building. A control room is located inside the Hat-truss and one operator controls all of the system.

2.4 Automated Steel Assembling System

In order to achieve a smooth setting of a load at a designated place, the shapes of various joints of steel structures had to be modified. Joints between steel column members and between columns and beams were modified to insert types, designed to realise free standing upon insertion. Photograph 4 shows a joint between steel column members.

Trolley hoists are equipped with hoisting jigs having automatic load releasing functions and which automatically unfasten hoisting wires after assembly of members.

In order to assure accuracy of the steel frames when assembling, an automatic measuring system using laser beams was developed and introduced on this project. A laser beam produced from a laser emitting apparatus set on the floor is received by a reception device installed at the top of the steel column and the inclination of the steel column from the reference line is detected. The detected value is digitised, and the operator on reading the value, corrects the inclination. This system is also used for measurements to ascertain the accuracy of a completed floor after completion of welding works.

2.5 Automated Welding System

Welding of column to column and beam to column of structural steel is done automatically using robots. The composition of the welding system between column and column is shown in Figure 4. The welding of a joint between columns would be horizontal multi-layered; three units of newly developed welding robots were introduced on this project. Photograph 5 shows a column welding robot in operation. The robot makes it possible to weld automatically whole groove of a column including corner portions in continuity. The configuration of a joint is detected by laser sensor, and work is done under optimised welding conditions referring to a data base. The robot proper is compact and light, weighing 19kg, and handling is easy. Because of the high level of automation, it is possible for a single worker to control 2 to 3 robots at one time, and therefore to result in reduction of required manpower.

Four special welding robots for joining together columns and beams have been introduced, and welding of beam flanges has been automated.

2.6 Automated Transportation and Installation of Prefabricated Materials and Equipment

Large sized precast concrete floor planks (fabricated in a PC factory), are automatically transported, and installed to the designated position, and the joints between two planks are filled up by concrete. Photograph 6 shows installation of a concrete floor plank.

In finishing and equipment works, beginning with industrialisation of interior finish materials, modularisation of exterior curtain wall panels, unitisation of equipment piping and pipe shafts, and packaging of equipment are aggressively carried out, and automated transporting and installation are done. Photograph 7 shows transportation of an exterior wall panel installed window pane and air conditioning equipment.

2.7 Information Control System

For the purpose of construction management of the entire job site, a computer integrated management system is introduced. Various systems such as those for labour safety control, quality control, scheduling, temporary equipment management, working drawings preparation, and overall construction co-ordination are operated through field office. The production control system is developed, which performs inputting construction procedures, compiling construction records, and monitoring the conditions of apparatus. The system is connected to the computer for controlling the SMART system.

3. APPLICATION OF THE SMART SYSTEM IN CONSTRUCTION OF THE NAGOYA JUROKU BANK BUILDING

The SMART system is first applied in construction of the Nagoya Juroku Bank building in Nagoya, Japan. The project was started in October 1991 and is scheduled to be completed by the end of February 1994. The building will stand 88 meters tall upon completion, 20 stories above ground and 2 stories underground. The total floor area measures 20,000 square meters.

3.1 Construction Procedure

The construction procedure in use of the SMART system is shown in Figure 5. When work on the substructures has been completed, the parts for the roof story (Hat-truss) of the building are assembled on the floor slab of the first story. Then, the conveying devices for the superstructure construction and weather protection cover are installed. At the same time, jacking towers for lift up are installed and lifting mechanisms are attached. Next, the Hat-truss is raised, and when this has been fixed to the top of the towers, assembly of the operating platform has been completed. Conveying members, setting them in position, and joining them are performed by this operating platform. When construction work for one floor has been completed, the entire operating platform is lifted up, and construction of the next floor follows. In this way, systematic construction, story upon story, is carried out, including interior / exterior finishes and equipment. When construction up to the uppermost story has been completed, all-weather protection sheets and the reinforced frames are removed, the Hat-truss is lowered and connected to the structural part of the building already constructed. Photograph 8 shows dismantling of the protection sheets. At the same time, the devices making up the operating platform are disassembled, and hauled out. When all the frames and devices have been removed, automated construction by the SMART system is completed.

3.2 Effects of the System

Effects realised due to use of the SMART system which have come to light through its application in the Nagoya project are as described below:

(1) Improvement of working environment

Through its all-weather protection (Weather Protection Cover), work can be performed safely and in comfort, without being affected by the weather. For example, welding can be done in a normal manner even on a rainy day. During the construction by the SMART system, approximately 20% of the period were rainy or windy days. However, there was no interruption of work due to weather.

(2) Elimination of dangerous and heavy work

Workers have been freed from operations with heavy workloads such as assembling structural steel and welding. Although not completely unmanned work, human works can be limited to intelligent work such as monitoring, maintenance, and quality assurance. Hazardous and heavy lab or has been made entirely unnecessary. Safety of work has been drastically enhanced through extensive introduction of automation and robotisation technologies, implementation of all-weather protection, and adoption of layered construction method.

(3) Reduction of man-hour on site

With effects of introducing computerised control and robotics, and also prefabrication and modularisation, it has been made possible for man-hour requirements to be reduced. It is estimated that for this project including structural, finishing and equipment works, a reduction of about 30% in lab or can be achieved. Especially, as for works which are involved in the SMART system, about 50% in lab or were reduced. (Figure 6)

(4) Reduction of working days for each floor

During the construction, the number of days required to complete each floor by the SMART system is greatly reduced from 9 days to 5 days at the last stage, due to the improvement of software pro gram, working method and practice of workers. It is expected about 20% to 40% reduction of construction period for the next application of the system.

(5) Reduction of workload on site management

The workload on site management personnel has been greatly lightened through introduction of a job site information management system controlled by computer. (6) Reduction of construction wastes

It has been made possible for construction wastes to be reduced through wide scale adoption of modularisation of materials and prefabrication. Comparing to the conventional site, about 70% (700 ton) of wastes were reduced in this project. Figure 7 shows the comparison of the construction wastes.

4. CONCLUSION

Through its application to the Nagoya Juroku Bank building, an outlook has been gained for realisation of a safe and comfortable work site unaffected by weather, reduction in labour and management requirements, elimination of hazardous and heavy workload operations, and reduction of construction wastes.

For further improvements in productivity, we must realise more reduction in manpower requirements and shortening of construction periods, even greater level of automation, and more intensification of industrialisation such as those in prefabrication, and constitution of an overall site management system. In the future, establishment of a building design suited to automated construction and realisation of an information system integrating design and construction programs, construction management, and construction operations will come to be sought.

It is from such a viewpoint that Shimizu Corporation is striving to upgrade the level of the SMART system to establish it as a building production system of a new image advancing toward the 21 st. century.

REFERENCES

1. Miyatake, Y.(1993)."SMART System: A Full Scale Implementation of Computer Integrated Construction",The 10th International Symposium on Automation and Robotics in Construction, May 1993

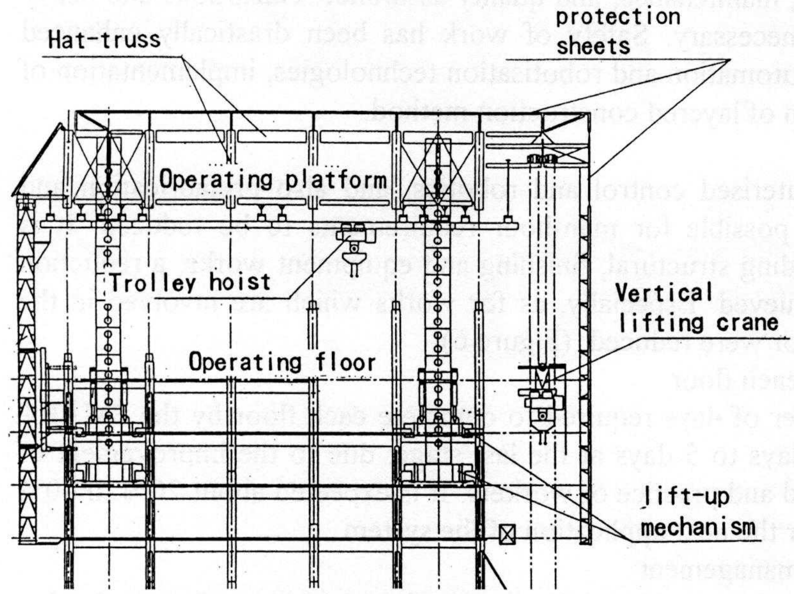


Figure 1. Constitution of the SMART system

Photo 1. Outside view of the Nagoya project

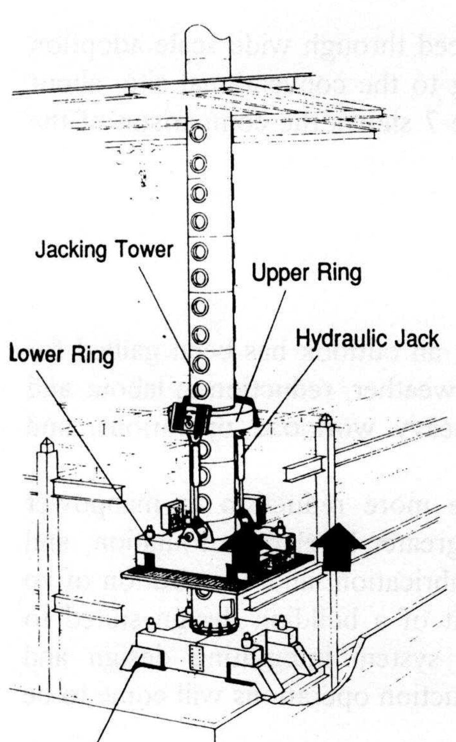


Figure 2. Composition of the lift-up system

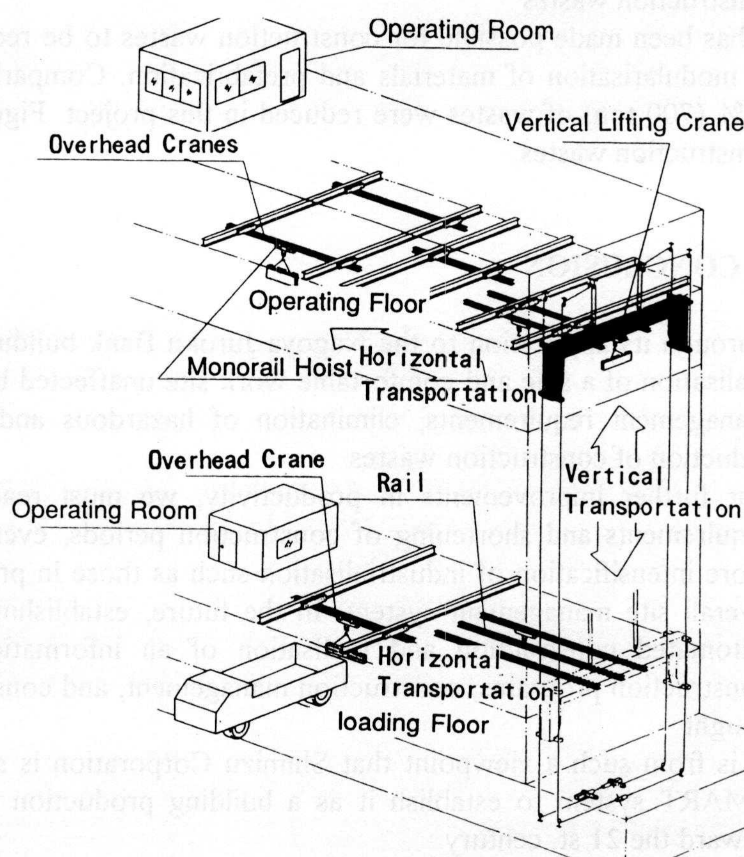


Figure 3. Components of the automated conveying system

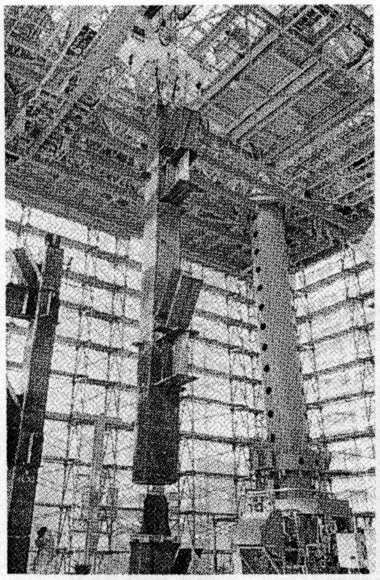


Photo 2. Steel column positioning

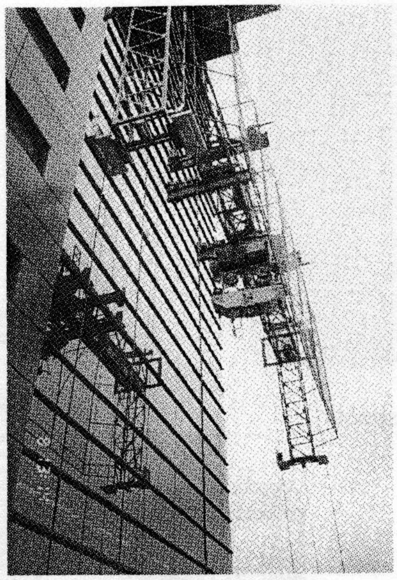


Photo 3. Vertical lifting crane

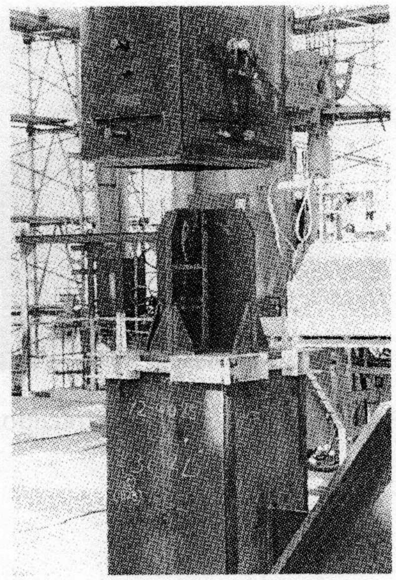


Photo 4. Joint between steel column members

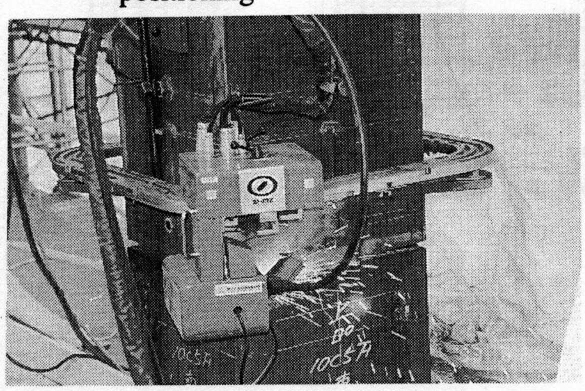


Photo 5. Column welding robot

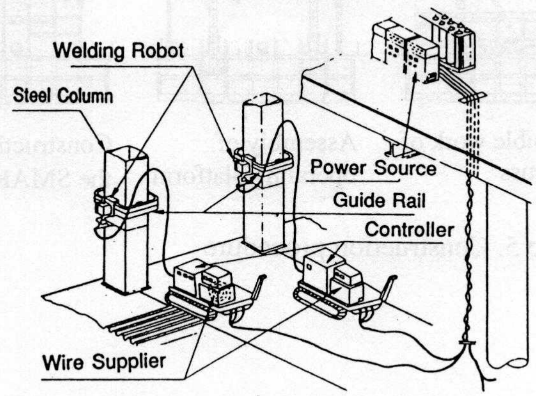


Figure 4. Composition of the welding system

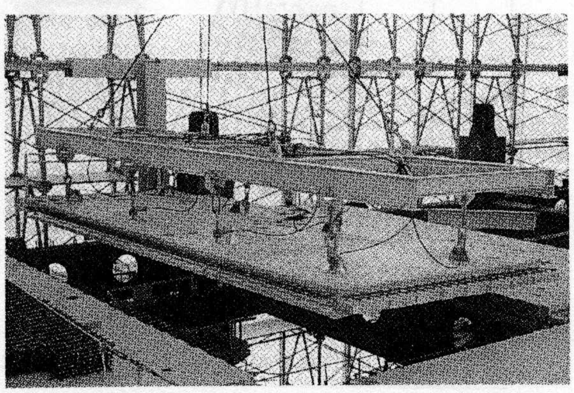


Photo 6. Installation of a floor plank

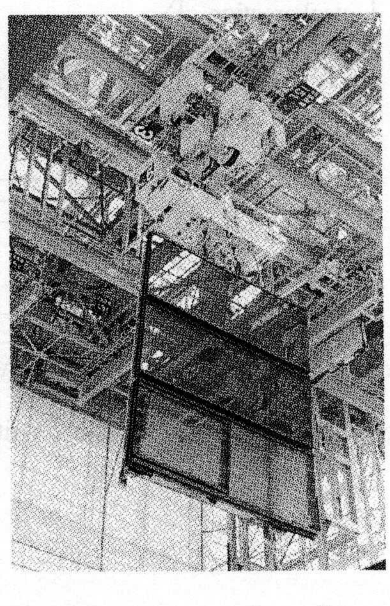


Photo 7. Transportation of an exterior wall panel

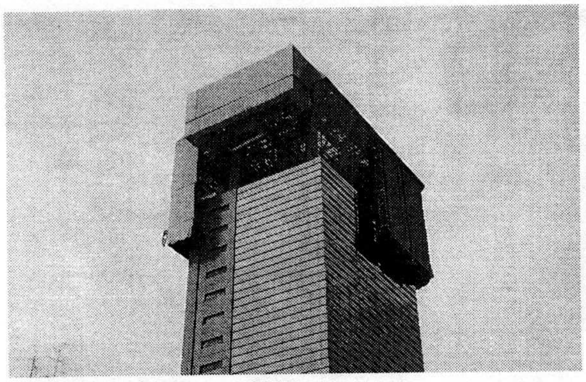
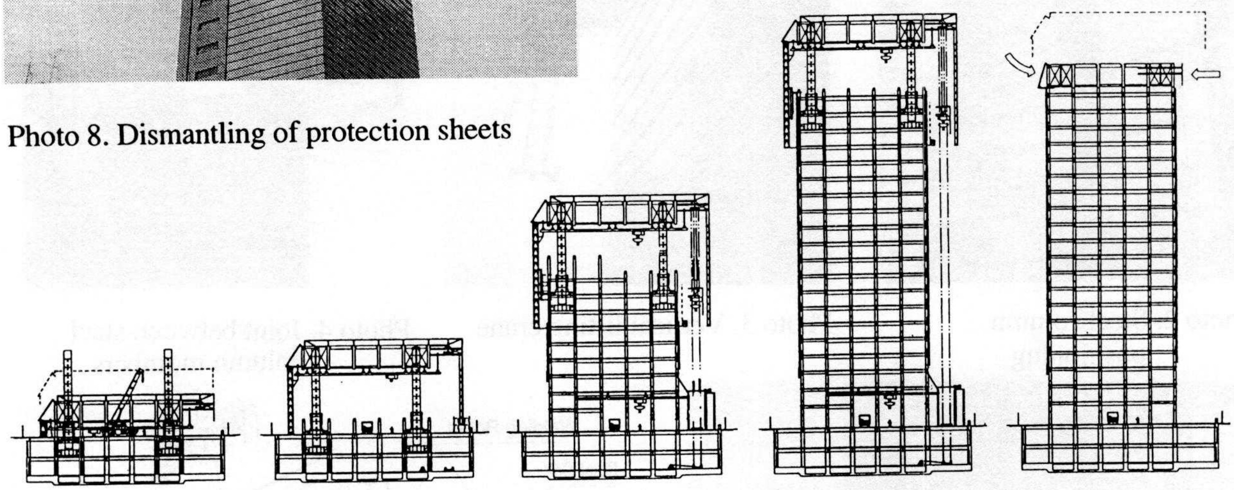


Photo 8. Dismantling of protection sheets



Assemble work of Hat-truss | Assembly of operating platform | Construction by the SMART system | Construction of uppermost story | Completion of construction

Figure 5. Construction procedure

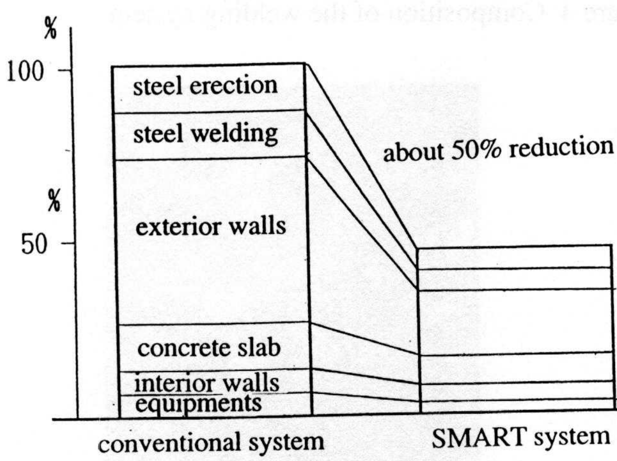


Figure 6. Reduction of manhour on site

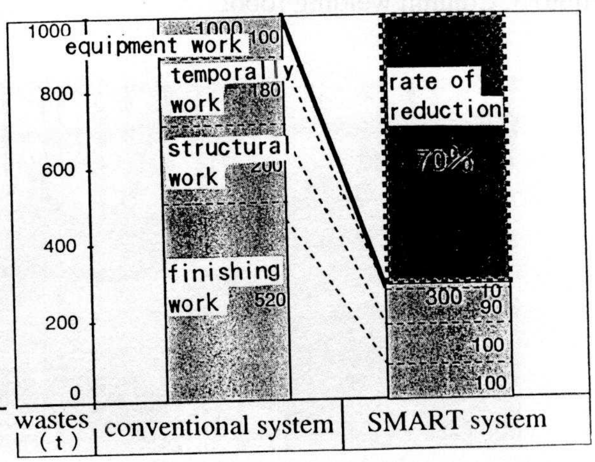


Figure 7. Reduction of construction wastes