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The body can be viewed from the next page.

CAD System for Fabrication of Steel Structures of Buildings*


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1 Introduction

With the competition for steel products becoming increasingly keen, production of high-quality products at a low cost in a short period of time has become indispensable to the survival of makers of steel structures. The rationalization of production by introducing NC machines, welding robots, CAD systems, etc. is being carried out using very efficient low-price computers and control equipment in the steel structure fabrication industry, which has long lagged behind in rationalization.

For this reason, Kawasaki Steel has conducted comprehensive studies since 1980 into the problem of the rationalization of fabrication at the Research Meeting for Automation of Steel Structure Fabrication with its subsidiary companies which fabricate steel structures and bridges. As a result, it was determined that it was urgent, necessary, and realistic to conduct rationalization using computers. In June 1983, the company's Engineering Division started the development of a CAD system for the fabrication of steel structures jointly with Shikoku Iron Works. Co., Ltd. Kawasaki Steel Systems R & D Corp. was in charge of software development.

The system which evolved an integrated system that generates shop drawings, full-size drawings and fabrication order sheets. The full-size drawing and fabrication control systems which were developed as universal production systems have been in use at the Marugame Works of Shikoku Iron Works since January 1985. The shop drawing system for building construction has been used at the same plant and in the Chiba Steel Structure Fabrication Center of KSC's Engineering Division as well.

This report describes the utilization of CAD systems in the Japanese steel structure fabrication industry, problems and basic policy in systems development, and an outline and the results of operation of the system which was developed. It also describes problems anticipated in steel structure CAD systems.

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2 Utilization of CAD Systems in Steel Structure Fabrication Industry

Steel structure CAD systems first entered the market in about 1982. Self-development by steel structure fabricators began at almost the same time. After that, the market for steel structure CAD systems came into focus when many steel structure CAD systems developed by software houses with capital participation by trading companies were adopted. Many companies began developing and marketing these systems, and this caused an increase in the introduction of steel frame CAD systems.

Although there is no accurate published data on the introduction of steel structure CAD systems, the authors' research indicates that CAD systems are in use at 79 (45%) out of 177 relatively large scale "H-grade" plants among the fabricators approved by the Japan Steel-Rib Fabricators Association (2 030 works authorized by the Minister of Construction as of April 1987). These systems are used at 100 (12%) out of 845 small scale "M-grade" fabricators and at 22 (2%) out of 1 008 "R-grade" works. The use of these systems is therefore steadily increasing. Steel frame CAD systems are very diverse in scope and can be divided into (1) systems used mainly for cutting templates using personal computers, (2) full-scale systems for shop drawings using minicomputers, and (3) integrated CAD systems for both shop drawings and full-size drawings using general-purpose computers. Due to the low cost of the equipment required, the number of systems using personal computers accounts for 66% of the total number of systems, followed by systems using minicomputers, which account for 30% of the total.

The system described in this report is classified under category (3) above as an integrated CAD system.

3 Problems and Basic Policy in System Development

3.1 Problems in System Development

The following three, problems were considered as basic to the development of steel structure CAD systems:

(1) The degree of design standardization is not high.
(2) The added value of drawings is low.
(3) Corrections and changes are made frequently.

The detailing of connections constitutes the main scope of design activities in a fabrication plant. Because details are different from building to building and from designer to designer, a system that processes all buildings, members and connections collectively requires immense man-hours for development and is, therefore, impractical.

Furthermore, the number of drawings required is

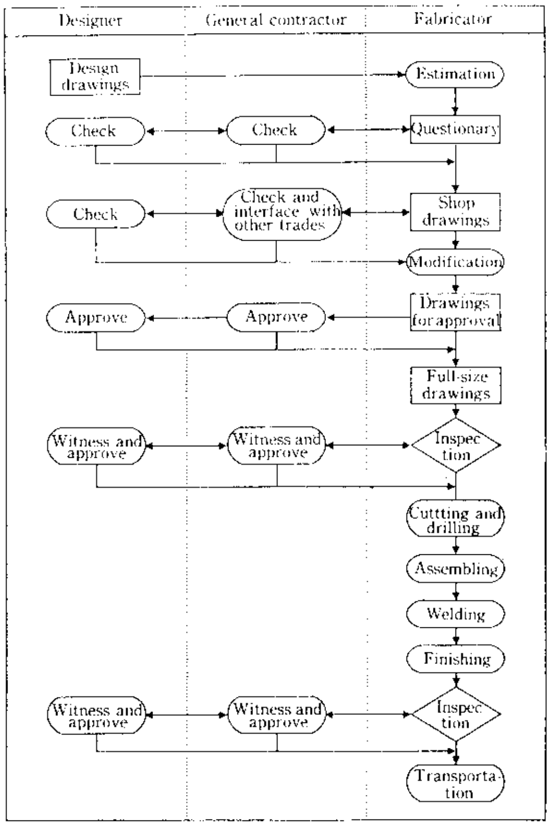

Fig. 1 Flow diagram to fabrication process

large because the number of structural members in a building is great, and it is necessary to prepare shop drawings for all members. Because of the low added value of products, the added value of the drawings themselves is generally not recognized, in spite of extensive amount of information contained in the drawings. Further, since buildings are designed individually, drawings are not normally reused.

Steel frame structures have primary structural members. In the job flow chart shown in **Fig. 1**, it can be seen that there are many interfaces with other trades, such as equipment work and finishing. In addition, steel frames require various small components (holes for reinforcing bars, duct holes, elevator fasteners, curtain wall fasteners, temporary construction members for erection, etc.). The design information on these small components is not yet definite at the point of time when the preparation of shop drawings has begun, and details must be determined through negotiations with designers and the general contractor after the release of the drawings. In addition, designs may be changed if tenant requirements change, requiring significant additions and corrections of drawings.

3.2 Basic Policy on Systems Development

3.2.1 High-speed mass processing

To process a large number of drawings at high speed, plotting is conducted by the collective processing of parameter input up to the stage of rough drawings (on which small components are not drawn). To concentrate input data, parts and joint data that can be listed are input collectively. To raise the degree of standardization of parts to which the system can be applied, main structural members (columns and girders) which have relatively few variations are processed collectively.

3.2.2 Flexibility by interactive CAD

A unique interactive CAD system for steel structural components was developed because flexible processing of each drawing is required during the finishing stage of drawings as with the above-mentioned drawings for small components, plotting of components with complex shapes that cannot be collectively processed, and layout correction, such as arrangement of letters.

To expand the range of components processed, a commercial two-dimensional general-purpose CAD system was used in the full-size drawing system developed earlier. The following deficiencies were found, however: ① The plotting efficiency was low when the commercial CAD system was used without modification. ② The processing speed was low, even if user macros of the commercial CAD system were used for programming. ③ Although the commercial CAD system had many functions and a large capacity, only some of the functions were useful for steel structures, while the capacities of both the memory and the disk were greater than needed. For these reasons the unique interactive CAD system was developed.

Besides its basic drafting functions for straight lines, circles, and dimensions, the newly-developed interactive CAD system can efficiently process steel plates and shapes as components so that it can be applied to bridges and other structures.

3.2.3 Ease of use

The system should be simple in operation so that opertors without detailed knowledge of the system or experience with it can use it after a short period of training without undue dependence on users' manuals.

Generally, the system flow is similar to that of conventional work and on-screen guidance (in Japanese characters) is frequently used. In the shop drawing system, the arrangement of members is processed in an interactive manner as if the operator were fabricating the structure as he sits at the display. Input can be checked by reference to the screen, which displays diagrams similar to beams in plan and framing elevations. In the fabrication control system, good operation is ensured by adopting a hierarchical menu screen.

3.2.4 Flexible data base

For the design of the data base, the collective control of graphic information and attribute (numerical) information was an aim of the initial stage of development. It was found, however, that the structure of the database itself becomes complex when troublesome changes must be handled, causing not only an increase in development load but also adverse effects on operation and response speed. It was decided, therefore, to adopt a database for each subsystem. Because the data base is sub-divided, the independence of each subsystem is high and large variations can be handled flexibly in actual application.

4 Outline and Effects of System

4.1 Hardware Configuration

The hardware configuration of the system at the Marugame Works of Shikoku Iron Works is shown in **Fig. 2**. The host computer is a UNISYS 2200/200S, to which four displays with 10-inch tablets and six character display units inputting data and displaying outputs are connected. An online electrostatic A1 size plotter for shop drawings and an offline XY A0 size plotter for templates are provided as output devices for the drawings. In addition, a paper tape puncher and a paper tape reader allow preparation of NC tapes.

Incidentally, the larger-capacity host computer was used for systems development in Tokyo.

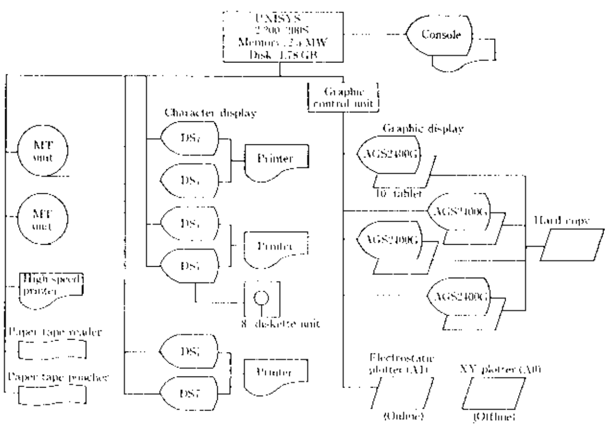

Fig. 2 Hardware configuration at Marugame Works

4.2 System Flow

This system is composed of three subsystems (shop drawing, full-size drawing and fabrication control) as shown in **Fig. 3**. These subsystems are so designed as to perform integrated processing simultaneously. In addition, a collective data input function is provided for each subsystem, and each can operate independently when complex design changes are made and when jobs are to be performed by cooperating companies.

4.2.1 Shop drawing system

The shop drawing system has the following five functions:

(1) Input of Reference Data

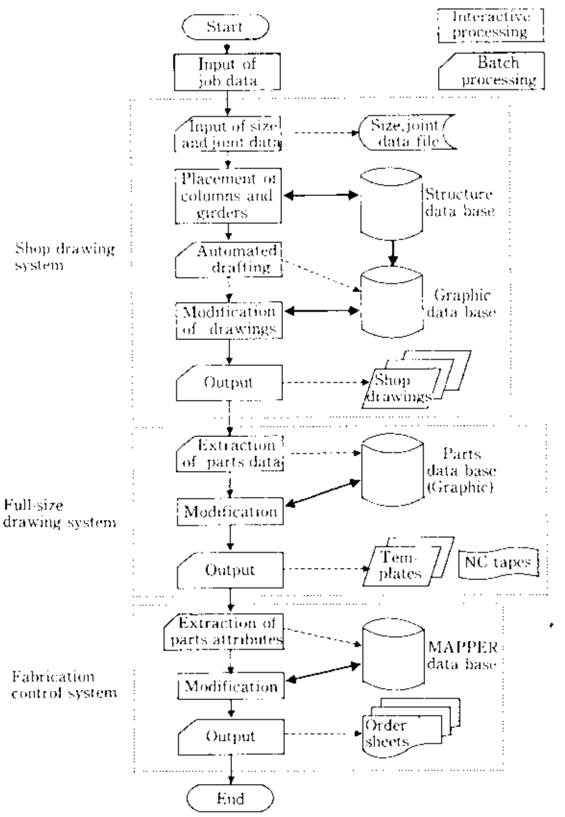

Fig. 3 Conceptional flow diagram for steel structure CAD system

After the entry of the work, data on member sections and data on joints can be obtained by reading design drawings, and data sheets are prepared and collectively entered.

(2) Input of Building Structure Data
The operator next interactively determines building line numbers, column spacing, the number and height of stories, and other standard building dimensions at the display, and arranges members such as columns and girders using the reference lines, while calling up design marks at the same time. The addition of joint positions, joint standard marks, top of steel below the finished floor, product marks, etc. enables the structural data for the entire building to be accumulated in the database. The data kept as original data for further processing. Operation is conducted by selecting commands on the menu sheet; input can be ascertained sequentially from beam plans and framing elevations, allowing quick mastery of the system by even inexperienced operators. A display of structural data is shown in **Fig. 4**.

(3) Automated Drafting
Higher speeds and labor-saving in the preparation of detail drawings are achieved by automated drafting involving collective processing by lot (tier and story). The plate of a column-girder connection is automatically generated by providing parameters

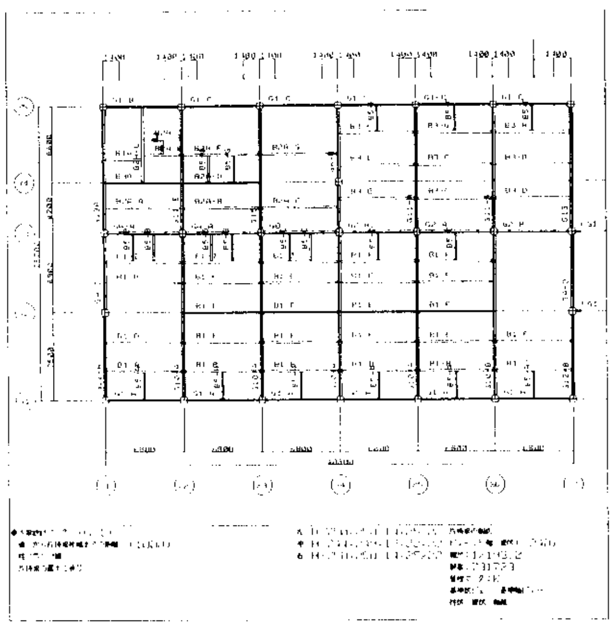

Fig. 4 Graphic screen for structural data definition

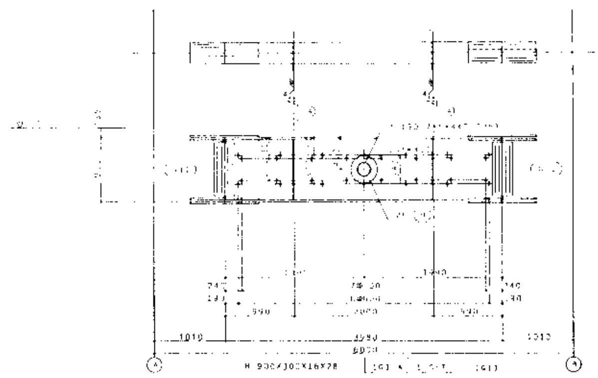

Fig. 5 Output sample of a portion shop drawing

when the processing is carried out, and the arrangement on paper is efficiently conducted by automatic processing. Drawings automatically prepared are stored on a disk and retained for modification instructions or output.

(4) Modification of Drawings
Detail drawings prepared by collective processing can be corrected and amended by an exclusive-use interactive CAD system for steel structures.

(5) Release of Drawings
Complete drawings can be output in groups for each member and lot (tier and story). A typical girder detail drawing of girder shown in **Fig. 5**.

4.2.2 Full-size drawing system

This is an interactive graphic processing system for generating templates and work lists. This system was developed based on a commercial general-purpose CAD system. The operator prepares templates and work lists by selecting commands from the display menu. During this operation, shape and attribute data is stored in the database.

Commands are divided into (1) special-purpose commands for each type of component, such as gusset plate and splice, (2) general-purpose commands for bolt holes, match marks, etc., and (3) basic drafting commands for straight lines, circles, etc. For the special-purpose commands, automatic processing is possible in addition to interactive processing if parameter files have been prepared.

Work lists are fabrication order sheets for cutting, boring and marking-off of steel shapes, and replace rulers to accomplish this measurement work. In this system, parts programs for an NC machine for steel shapes are prepared from work list data; NC tapes are prepared by adding material interface information.

4.2.3 Fabrication control system

Attributes such as thicknesses, material properties, and number of holes in components, and structural information such as shop drawing numbers and the names of products and components, are extracted from the full-size drawing system, and a data base consisting exclusively of numerical information is prepared by collating this data. This numerical database on components is used as the original data for production information, and is applied to various tasks such as fabrication instructions, production planning, and follow-up control.

Because the data base is composed of numerical information, the processing load is reduced, database control is simpler, and design changes arising as late as the fabrication stage can be handled flexibly.

The output menu of the fabrication control system is shown in **Fig. 6**. The information includes pre-working equipment (for cutting and boring), fabrication work, and lots, and thereby makes it possible to provide detailed instructions for fabrication, e.g. "parts to be worked by an NC machine for steel shapes in the girder of the first tier."

The general-purpose spreadsheet program MAPPER (Nippon Unisys) is used for database control and preparation of fabrication order sheets. This program was adopted because development efficiency is high, on-screen menus can be freely designed, and access to and working of the database are easy when using interactive commands and macroprograms prepared by the user, providing high expandability.

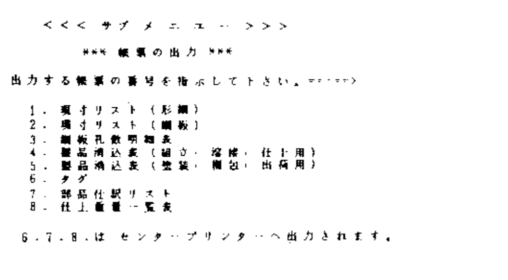

Fig. 6 Output menu of fabrication control system

4.3 Results and Effects of Operation

The full-size drawing and fabrication control systems were brought into operation in January 1985 and are now used in processing almost all the steel structures fabricated at the Marugame Works (more than 50 000 t in the past three years). They have become standard production systems of the Works. The fabrication control system which was put into use in June 1986 at the Chiba Steel Structure Fabrication Center of KSC and at the Marugame Works of Shikoku Iron Works has processed more than 20 000 t of steel structures.

In the upstream departments for the preparation of shop drawings and full-size drawings, the number of personnel was reduced after the adoption of the system and efficiency increased by abouut 30%. At the same time, the load for maintaining and managing production information increased, especially for database corrections resulting from design changes. In the planning department in which production information is used, the amount of work related to addition, totalization and transfer decreased, resulting in an increase in productivity of about 50%.

The following ripple effects were also observed:

(1) The division of fabrication lots became clear and the process was executed more smoothly.
(2) Instructions were more clearly defined because fabrication order sheets can now be output for each work item and process rapidly.
(3) Errors in transfer and calculation and discrepancies between sheets no longer occur.
(4) Data results can be easily obtained and utilized for calculation, planning, and management.

The greatest effect, however, is the fact that technical services from the planning department to the production departments were improved due to the decrease in the office work load for the planning department. **Photo 1** shows the computer room at the Marugame Works of

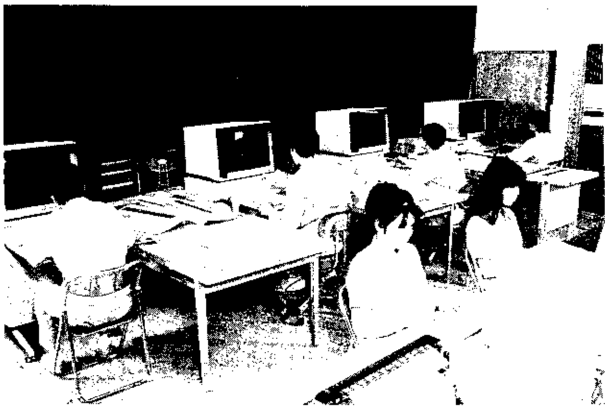

Photo 1 Terminal operation in Marugame Works

Shikoku Iron Works.

5 Problems with Steel Structure CAD Systems

Many shop drawings are prepared by CAD systems presently worldwide, indicating the general acceptance of the CAD concept. These CAD systems, however, should be regarded as first-generation CAD systems. It has only recently been determined that such systems can be used in practical applications, and many problems remain to be solved, even with the current systems. The main problems with current systems, including that developed at KSC, are described below.

(1) High Price: The price of hardware, especially of peripheral devices such as plotters and disk devices, is high. Further, the ratio of software development cost is high because the anticipated number of units sold is estimated conservatively. Recently, systems using engineering work stations (EWS) have appeared, and full-scale systems using high-performance personal computers have also been introduced. it is expected that a wide range of system configurations which use these high-performance, low-price new machines and are adaptable to local area networks (LAN's) will be developed in the future.

(2) Limitations to Functions: Commercially available systems are divided into shop drawing systems for building construction and full-size drawing systems. Although each of the groups is now in practical application, few systems are capable of performing integrated processing of shop drawings to templates or NC tapes and can also be adapted to design changes, and at the same time are practical in terms of cost.
Recently, NC data preparation systems and material calculation systems using personal computers have appeared on the market. One realistic solution is use of these systems as support systems, in view of data compatibility.
Systems based on universal-purpose CAD have also appeared. High efficiency, however, cannot be ensured unless the system is developed especially for application to steel structures. It is expected that the development and advance of universal-purpose CAD systems for steel structures will be implemented with cooperation between computer manufacturers and users.

(3) Lack of Competent Operation Managers: Steel structure CAD systems are still being improved and, therefore, the effect of their introduction varies greatly depending on the abilities of individual operators. Because of the structural depression after the oil crises, the employment and training of young enthusiastic engineers has lagged, while at the same time it is difficult for managers to obtain an objective grasp of a variety of systems. Systems are tools, after all, and how to train operators is a major problem for the future.

6 Conclusions

Thus report has described how the fabrication of steel structures by a CAD system was rationalized. The features of the system may be summarized as follows:

(1) This system is composed of shop drawing and fabrication control subsystems and is also an integrated system for production information control.
(2) In the shop drawing system, efficient and flexible drafting is obtained by combining high-speed processing of a large number of drawings using automated drafting with interactive input and correction processing.
(3) In the full-size drawing system, parts information is accumulated by preparing templates and steel shape working lists on the screen. NC tapes are prepared based on this information.
(4) In the fabrication control system, information on parts attributes is stored as a database. This system is used for many applications, such as giving fabrication instructions, production planning, and follow-up control.

This CAD system has gained wide acceptance in plants. Production itself changes, however, depending on surrounding conditions, and systems become obsolete unless they are modified to adapt to these changes. For this reason, no production system represents the final and complete stage of development. At present, the functions of the interactive CAD system are being enhanced and a plan to transplant the system into an EWS is being made. Attempts are also being made to enhance the linkage of the CAD system to the material control and process control at fabricator plants. In the future, CAD data will be used in production systems with welding robots, and factory automation of the entire plant is considered a feasible goal.