Steel and Composite Structures, Vol. 3, No. 1 (2003) 13-32
DOI: http://dx.doi.org/10.12989/scs.2003.3.1.013

CALS oriented design/fabrication information system for steel bridges

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(Received August 20, 2001, Revised December 29, 2002, Accepted January 14, 2003)

Abstract. In this paper design and fabrication information system for steel bridge construction is studied and proposed according to the progress of Construction CALS/EC in the construction industry in Japan. The data exchange in this system bases on the text file as well as CAD data with simplified drawings. The concept of this system is discussed following the analysis on the issues of the conventional system. The application of the product model is also discussed including effects and issues on the inspection system. This paper is based on the study carried out by Special Committee on Construction CALS of JASBC to which author belong.

Key words: CALS/EC; steel bridge; fabrication; data exchange; auto CAD; CAM; inspection; product model.

1. The background and purpose of the study

The research of the introduction of CALS to public works/construction industry in Japan began substantially after the Committee on Construction CALS/EC being established in May 1995 by the Ministry of Land Infrastructure and Transportation. In April 1996 the MLIT launched “The Basis Idea on Construction CALS”. It was aiming to commercialize Construction CALS/EC by 2010 in the field of the public works. Furthermore, in June 1997 the MLIT set “Construction CALS/EC Action Program” and they hastened the goal year of the commercialization of CALS/EC from 2010 to 2004 (Akeno 1997, Shimazu 1998, Shimazu 1999).

The contents of Construction CALS/EC can be divided largely into two parts. One is the part

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regarding electronic procurement. This part covers procedures of contracts for public works such as disclosure of tender information, electronic tender, electronic attestation etc. Another is the part regarding electronic delivery. This part covers drawings, Bill of Quantity, statement of accounts, business reports and other construction work completion literatures produced as results of execution of contracts. About electronic delivery, the MLIT has already issued the specification of the electronic delivery for the completion literatures.

The research and development on Construction CALS/EC has been carried out so far mainly by the consortia composed of construction enterprises, consultants, system houses and the MLIT. However, the aim of this research and development is limited to prescribe the frame of Construction CALS/EC for the whole construction industry from the owners' point of view. As for the research and development individual study on the information system in Construction CALS/EC according as the technical characteristics of each construction industry is inevitable from the contractors' point of view.

Steel bridge construction industry has been treating data in the form of digital from the earliest days among the construction industry. The development began from the beginning of 1970's (Takaku 1985). This originates from the particularity of steel bridge construction industry that more than half of the construction work belongs to the fabrication in factory.

About 30 years have already passed since the numerical control (NC) machines have been introduced to the fabrication of steel bridges in the processes of steel plate cutting, bolt hole drilling and piece assembling in factory. In this 30 year history, the function of Full Size Drawing process has been changing completely from drawing of actual figures on floor to data processing on desk to transfer the analog data, in other words, paper drawing into digital data, which has realized the production systems based on the digital information in the field of steel bridge superstructure construction.

The development of the new design/fabrication information system in steel bridge superstructure corresponding to CALS/EC should be practical according to the achievements mentioned above.

In the study of Mikami *et al*. (1999), they propose the method that DXF file format generated from Auto CAD, developed by Autodesk Co., is transformed into file format by Part21 of STEP.

The method of the data exchange, now under developing by SCADEC (Standard CAD Data Exchange Development Consortium) and expected to be standardized in future in Japan conforms to the international standard, STEP/AP202 (Part 21), ISO10303. This method is aiming for high exchangeability of drawing data output between different CAD systems (SCADEC 1999). Either method is trying to exchange CAD data as it is in the form of CAD drawing.

On the contrary, the method proposed in this paper is design/fabrication information system based on the data exchange in the form of text file as well as CAD drawing.

In this paper the concept of design/fabrication information system is described following the analysis of the issues in the conventional system. Then the form and flow of the design data and the structural design model are mentioned as well as the linkage to the three dimensional fabrication data (product model) from digital data generated in the design stage. Inspection system is also discussed under the new design/fabrication information system.

This paper is based on the study carried out by Special Committee on Construction CALS of JASBC (Japan Association of Steel Bridge Construction) to which the authors belong since 1997. The reports published in the past (Isohata 1998, Hara 1999, JASBC 2000) discussing the theme in this study were announced as partial research results which we got respectively until the time. This paper integrates these reports adding new research results and consideration.

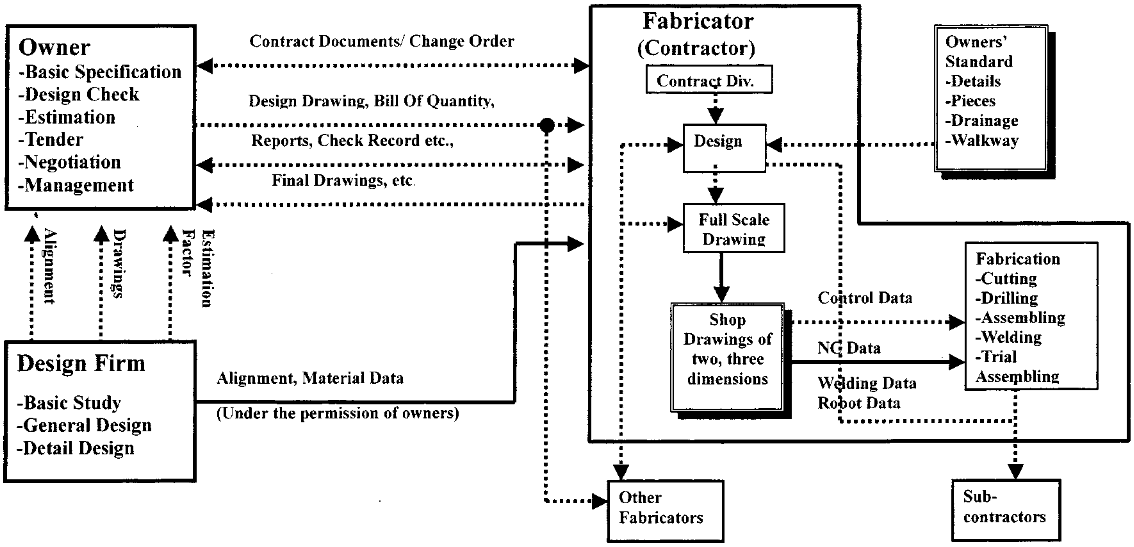


Fig. 1 Conventional data exchange in the construction work of steel bridge superstructure

2. The current issue on the design and fabrication data exchange

Most consultant firms make up the documents such as drawings, bills of quantity and alignments in the form of digital. However the information exchange between consultant firm and owner, owner and contractor are carried out in the form of paper as traditional medium. Fig. 1 shows the situation of the conventional data exchange in the construction work of steel bridge superstructure.

Although the most of drawings have changed from handwriting to auto drawings by CAD software, the data exchange of drawings still depends on papers. The followings issues are conceivable for these reasons.

- The restriction on the transformation from the design drawing data to the fabrication data.
- The delay of the standardization of the structural details.
- The indefiniteness of the responsibility range on the quality of CAD data.
- The problem of CAD software.
- The problem of CAD data exchange medium.

If the digital information generated by the design work can be utilized with the fabrication process as it is, the productivity of the whole steel bridge construction work will improve substantially. For the direct data exchange in digital between design and fabrication especially the first three items in the above should be solved.

The first issue in above, the restriction of the transformation from CAD data to the fabrication data is mainly caused by the way of expression in the conventional design drawing which does not orient only for the fabrication. As shown in Fig. 2, only 10% of the data on the design drawings can be utilized for the NC data for fabrication directly.

The pieces and members of bridge superstructure components on the design drawings are not shown in the size of fabrication but of final completion stage. To convert to NC data for fabrication the allowance for camber and deformation by welding, assembling etc., must be added on the design drawings. Another restriction on the transformation of the design drawing is caused by the way of

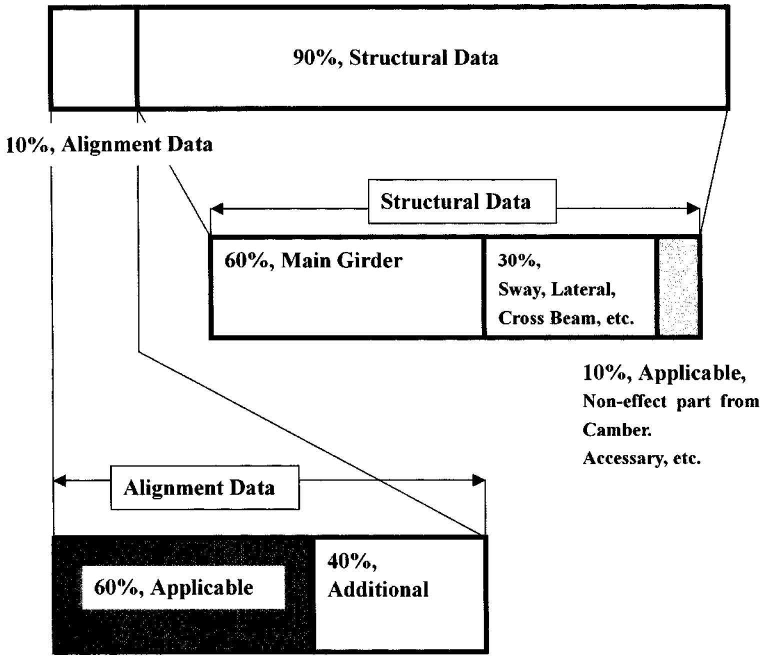


Fig. 2 The proportion of drawing data utilized for the NC data

expression of drawings. In conventional drawings, for the purpose of better understanding for human eyes sometimes thickness of steel plate are drawn in exaggerated scales, structural details are drawn in free scales and only half part is drawn in case of symmetric structures. And also since the conventional design drawings is information of two dimensions, the direct data exchange from design drawings to fabrication data of three dimensions is not easy and requires a lot of additional information. This point is the biggest reason why we propose in this paper the method of the data exchange by text files as well as CAD data.

The second issue, the delay of the standardization is caused by the difference of the standard of structural details owner by owner and the ambiguousness of the binding force of the each standard. Because of this the consistent standardization through the each stage of design, fabrication and erection is not advanced and the economization of the whole steel bridge construction work is hindered.

The third issue, the indefiniteness of the responsibility range on the quality of CAD data is indefiniteness of the responsibility between owner, consultant firm and contractor. Confusion may continue to happen in the fabrication stage, if the range of the duty and responsibility to check drawings and other documents generated in the design stage is not clarified. The current design drawings are expected to include the information close to the shop drawings with structural details, which should be determined under the condition of fabrication and erection methods. The drawings always accompany the risk that supposed conditions for the fabrication or erection at design stage may be incorrect or not be practical. Contractors owe the duty and responsibility for check on the design drawings by the contract. However in case difficulty in fabrication or erection caused by design such as the interference and execution of the members and pieces of components are occurred the whereabouts of the responsibility are indefinite in conventional system except simple errors or mistakes.

The forth and fifth issues are the matter belongs to the development in the field of IT. In this new system author aims for the direction which especially the first and second issues will be solved. The third issue will be solved through the improvement of the first and second issues.

3. New bridge fabrication system

3.1. Concept of new system

The data exchange of the information on the drawings cannot be materialized only by digitalizing the two-dimensional image on the conventional drawing as it is. Text file data exchange is applied in the new bridge fabrication system as well as CAD data exchange with simplified drawings.

The bridge types dealt with in this new system are plate girder and box girder with RC slab, the most popular bridge types in Japan.

The concept of the new system is gathered to the following points.

- Separation of conventional detail design to “SD” (Structural Design) and “SDD” (Structural Detail Design).
- Setting of “SDM” (Structural Design Model) as standard structural data file.
- Standardization of structural details.
- Setting of drawing for SD (Simplified drawings).
- Material list for estimation (Bill of Quantity).
- Introduction of product model.

3.1.1. Separation of conventional design to SD and SDD

The design of steel bridge superstructure now carried out by consultant firms are composed of SD and SDD. The contents of SD are the structural skeletons, basic structural formation, elements of alignments and structural analysis.

The arrangements of joints and stiffeners, cross section and thickness of steel plates are determined in SDD. Recognizing as three-dimensional structure by the combination of the information of cross section and alignments the discrepancy and the interference of the relation of the members are checked and modified if necessary. This includes reinforcement of members for the erection and consideration on the relation with the accessories such as drainpipes, railings expansion joints etc.

In conventional way, fabricators generate fabrication data of three dimensions after they check the drawings made by consultant firms and supplied by owners as contract document. This means that more than half of the structural detail design is carried out firstly by consultant firms and later by fabricators again.

Basically SDD is subject to SD. Only SD, fundamental part of the design information should be included as contract document and SDD should be carried out after the construction starts. Since the quantity of information of both SD and SDD are voluminous, it is useless that the “heavy information” is exchanged repeatedly between owner and contractor as contract document for the procedure of checking report and approval. The separation of SD and SDD in this system brings about apparently far more efficiency than the conventional way from the viewpoint of data exchange

The contents of SD and SDD are respectively as follows.

SD (Structural design)

- Alignments calculation
- Structural design
- Structural design model preparation

- Calculation of Material List for estimation (Bill of Quantity /estimation).
- Preparation of drawing of SD

SDD (Structural detail design)

- SDD data preparation (Product Model/completion)
- Addition/modification of SD drawing.
- Addition/modification of Material List for estimation.

Table 1 Items for standardization

Standardization of decision making
- Shift of welding joints of main girders - Length of stiffening sections at bolt joints - Connecting points of skeleton for cross beams and sway bracings - Connection between main girder and cross beams - Gusset plates of lateral bracings - Bolt arrangement for lateral, sway bracings and girder - Connection of main girder and sub girders - Shape and strengthening of manholes - Strengthening of eck holes for drain box - Connection of electric cables - Welding standard - Shape and connection of stringers - Hock piece for maintenance work - Connection and shape of shear connectors, slab anchors

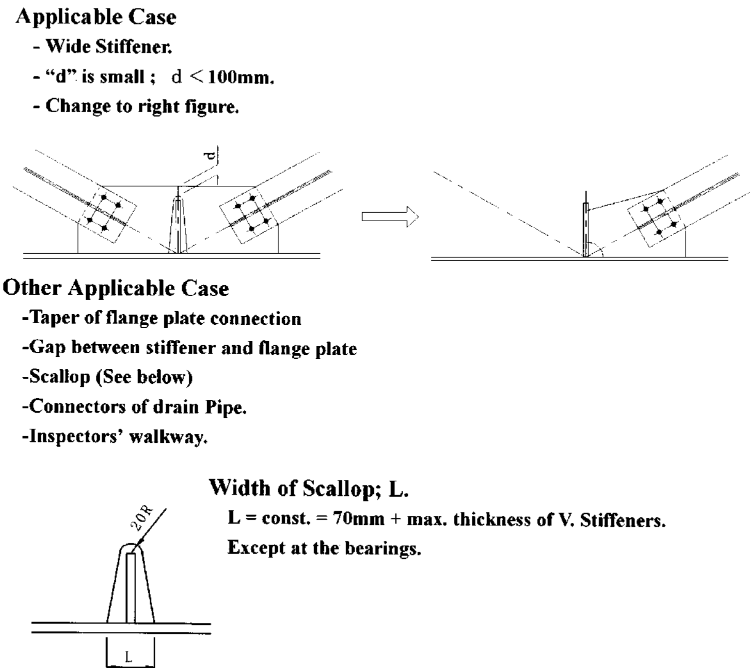


Fig. 3 Example of the standardization

3.1.2. Standardization of structural details

The standardization is most important for the promotion of this new system in CALS/EC. The standardization includes not only the figures of components but also the process of decision making for the design of structural details. For the standardization of steel bridge superstructure it is important to treat the interference with the adjoining pieces or members in the process of detail design.

Table 1 shows the item of the standardization and Fig. 3 shows the example.

3.1.3. The standard data file between SD and SDD

The digital data between SD and SDD is exchanged by text data as well as drawing data. For the purpose of data exchange by text file SBI format (Standard for Bridges Information Format) is set up as the standard data file in SDM. In the standard data file in SBI format, the rule for the standardization of structural details and design intention are included. ASCII format is adopted for the method of expression.

The standard data file by SBI format is composed of alignments data and structural design data. Table 2 shows the contents of standard data file. SBI format for alignments data, structural design data, material data are shown in Tables 3 to 5 respectively.

3.1.4. Drawing of SD

It is impossible that the transmission of all the design information is rely on only the form of text file data. Therefore the design drawing cannot be abolished in this new system. Drawings have the role as contract documents as well and change order is based on the drawings with Bill of Quantity. And also the drawings supply the visual information for the erection plan.

As shown in Figs. 4, 5 results of SD is included into the drawing of SD strictly. No other information can be allowed to include. In conventional drawings, main structures are expressed in the scale of about

Table 2 Contents of standard data file

Standard data file for plate girder bridge	
Alignment data	
- Road alignment	- Elements of alignment
- Section	- Profile
- Girder skeleton	- Girder depth
Structural design data	
- Main girder	- Coordinate of main girders
- Haunch	- Depth of main girders
- Camber	- Cross section of main girders
- Arrangement of stiffeners	- Section of V. Stiffeners
- H. Stiffeners	- Splice
- Bearings	- Shear connectors, slab anchors
- Cross beams	- Sway, lateral bracings
Structural standard data Material data Design condition data Slab data Road data (pavement, railing etc.) Structural analysis data	

Table 3 SBI format for alignments data

SBI Format (Alignment Data, 1/2)
Basic points

SBI Format version No.	System Code

Title		
Block		
Span	type	Slab
Co-ordinate	X	Y
Line No.		

Attribute 1	Attribute 2	Attribute 3	Attribute 4

Other lines ⇨

Section No.		
Attribute 1	Attribute 2	Angles

Line No.	X	Y	Height	Section	Distance	Width	Angles	Pavement	Adjust	Slab	Haunch	Web top	Depth	Web bottom

Repeat by number of points ⇩

Table 4 SBI format for design details

SBI Format (Structural design)

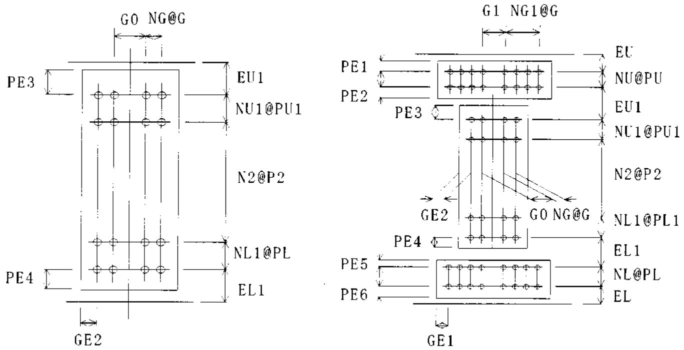
SBI Format version No.	System Code

T: Thickness of plates
M; Grade of Materials

DATA WEBSPLICE

Grope No.						
Number	S-PL, T	S-PL, M	M-PL, T	M-PL, M	Fil-PL, T	Fil-PL, M

G0	NG	G	G1	NG1	G2	GE1	GE2	PE1	PE2	PE3	PE4	PE4	PE 4
EU	NU	PU	EU1	NU1	PU1	N2	P2	NL1	PL1	EL1	NL	PL	EL



1/20 covering whole part of structures from girders to all the pieces and accessory including structural details.

On the contrary, the drawings of SD are simplified drawings based on the standardization of structural details. The contents of the drawings are composed of the key plan showing the arrangement of the whole structure and each structural detail based on standardization. The number of sheets of

Table 5 SBI format for material data in

SBI Format (Material List)

SBI Format version No.	System Code

Layer No.	Layer Name	Number	Piece No.	Code V	Code H	Comments

Code	Size1	Size2	Size3	Size4	Length	Number	Unit W	Net	Material	Name	Comments
Hour	Weld L	Unit W	Paint Code	Code V	Code H	Comments					

Shape Code and sizes of section

Name of Shape	Shape Code	Input Items
Steel plate	PL, APL, HPL, AHPL, PLS	W×T
Flat bar	FB	W×T
Angles1	L	H×W×T
Angles2	L	H×W×T
Angles3	L, LL	H×W×h t ×HT
Channel	C, CL, CH	H×W×h t ×HT
I-section	I	H×W×h t ×HT
H-section	H	H×W×h t ×HT

Estimation Element Code

Kind elements	Code	Member
Large piece	L	Flange, Web plate, Deck plate, etc.,
Small piece	S	Stiffener, Splice plate, connections, etc.,

drawing decreases about 1/10 - 1/ 5 in comparison with conventional drawings. The example of plate girder expressed in the drawing of SD is shown in Figs. 4, 5.

Fig. 4 shows main girder. The skeleton in plan of the whole part of bridge, names of members, composition of main girders and the contents of stress diagram are shown in the form of table. One whole main girder is drawn in one sheet of drawing and the number of sheets required for the main girders is only the number of main girders.

Fig. 5 shows structural details of main girders. All members and pieces in the drawings are drawn referring to the Book of Standardized Details (Takaku *et al.* 1994). The drawing is to be exchanged according to the data format (ISO/STEP-AP202) now under developing by SCADEC.

3.1.5. Material list for estimation

Material List (breakdown of Bill of Quantity) has the role of contract document with drawing of SD. In this system SDD is to be carried out after the contract. Before the contract, however owners need Material List for the estimation of tendering. Material List for estimation is made up for the purpose of the estimation as well as drawing of SD.

In conventional Material List each piece of material is picked up one by one from detail drawings. On the contrary, Material List in this system is based on the drawing of SD and calculated as common and standardized pieces and members.

3.1.6. Introduction of product model

In the latter part of the data flow of this system, the product model is introduced. Product model is defined as integrated production database, which deals with all the information regarding the fabrication as a whole. The product model is composed of all the information related to the data of

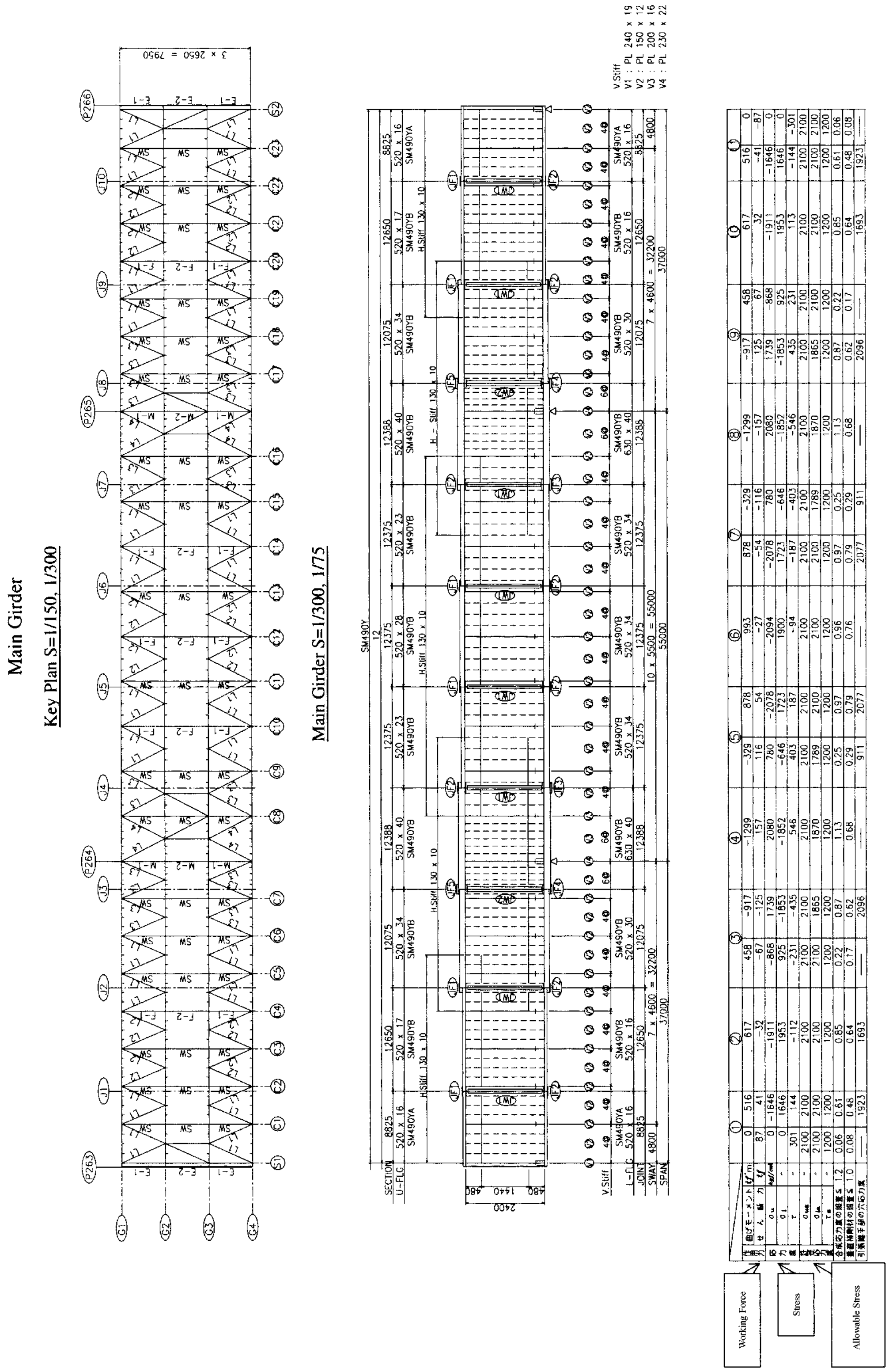


Fig. 4 Drawing of SD (a main girder)

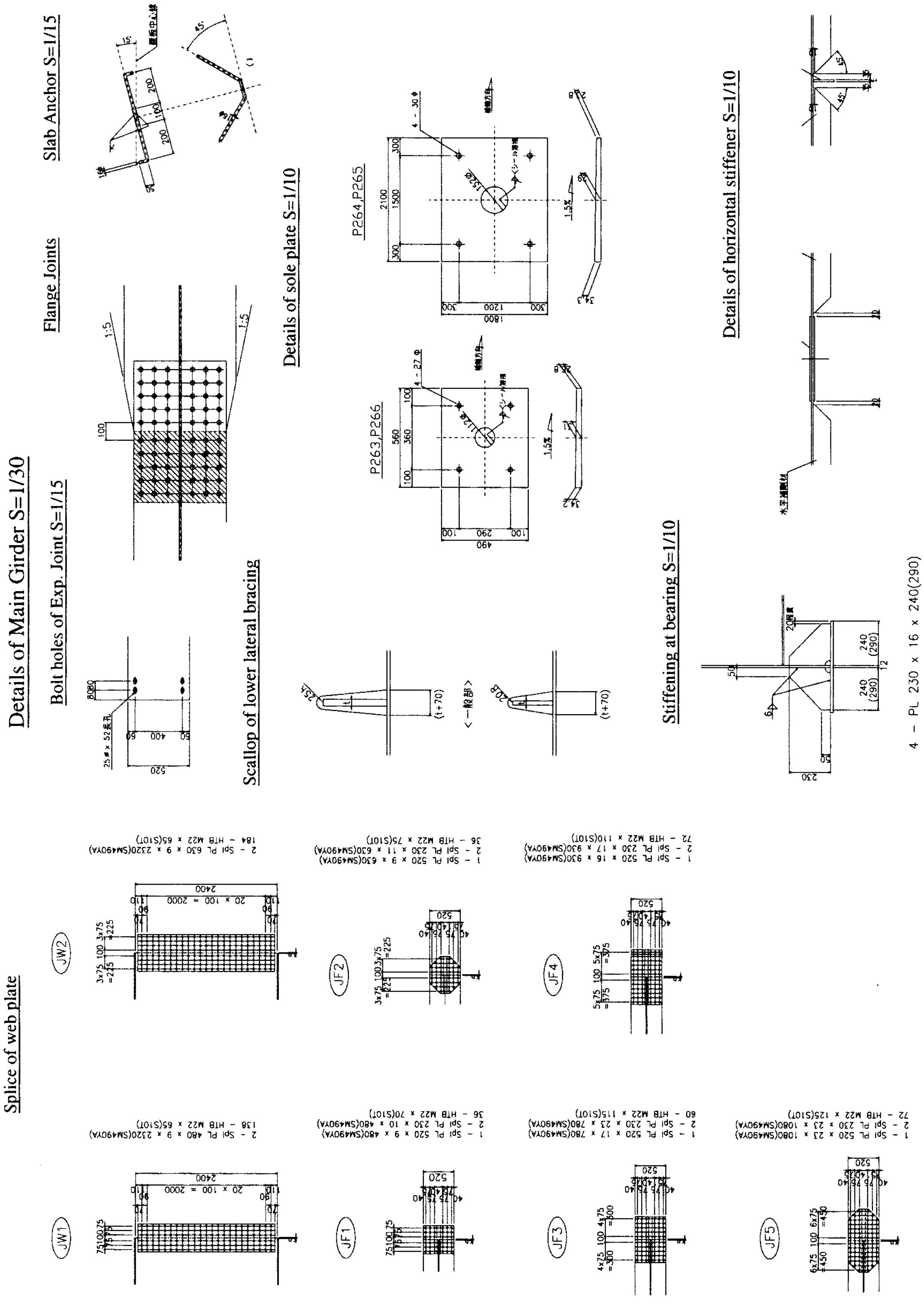


Fig. 5 Drawing of SD (Details of splice etc.,)

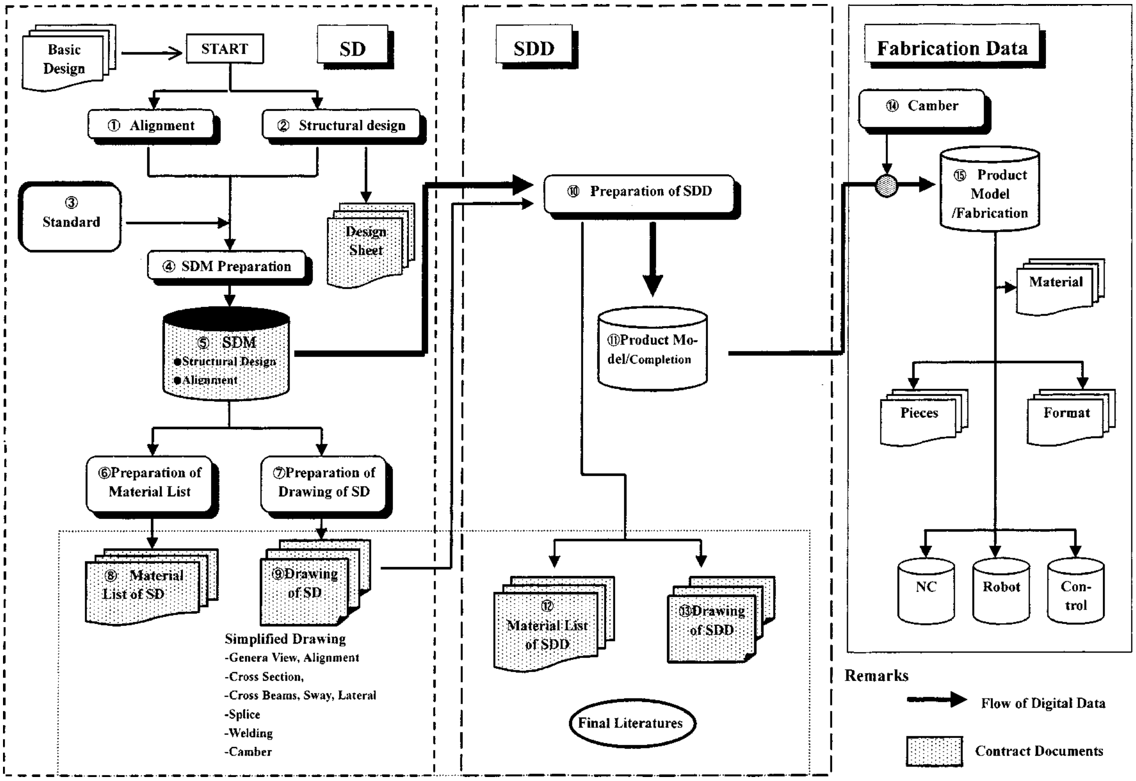


Fig. 6 Data flow in the new bridge fabrication system

the measures and sizes of structures and attribute of members and pieces of the structures for fabrication.

3.2. Data flow in the new bridge fabrication system

According as the maturity of the information SD comes first in the data flow followed by SDD and the fabrication information preparation (Fig. 6). In this flow consultant firms are in charge of SD and fabricators carry out SDD and fabrication information preparation according to the scope of the contract.

3.2.1. Structural design; SD

In the alignments calculation work (①, Fig. 6) the structural alignments is decided according to the condition of the given road alignments. The shape of the structure is defined by coordinate values of three dimensions at the points of top and bottom of web plate where sway bracings or cross beams are connected or the girder is spliced. In the structural design (②) each part of the structural details such as cross section of girders, stiffeners, sway bracings, lateral bracings, splices and welding detail are to be determined by conventional auto CAD or design software.

By reflecting the result of the standardization of structures (③), design of each structural detail can be decided more efficiently. The design calculation sheet is made with the same form as the conventional one. The standardization (③) located before SD preparation work in the data flow plays the supplementary role for the design.

The information of standardized pieces and members is delivered to SDM through SDM preparation work (④). Also, the standardization makes it possible to check the interference of members and generate the product model effectively in SDD work located in the latter part of the flow. In future standardization will occupy an important position for the systematization of drawing of SD preparation work (⑦) and calculation of Material List (⑧).

SDM preparation work (④) is the work that generates SDM (⑤) in accordance with a standard format on the basis of the result of SD. SDM is composed of alignments data and structural design data.

Alignments data is composed of three-dimensional coordinate data generated by the alignments calculation work (①). Structural design data includes the information on main girder such as depth of web plates, thickness of web and flange plates stiffener, splice, grade of materials and bearings, cross beam and lateral bracing data and standard data which are decided in the structural design (②). In each case, the text data is housed in accordance with the SBI format.

In the calculation work of the Material List for the estimation (⑥), weight of steel plate by each material grade, number of pieces, number of bolts, total nominal length of welding, aria of painting are calculated according to the drawings of SD and SDM (⑦) which are the elements of the standard of the estimation for the public work.

There are some pieces such as gusset plates, which exact shapes are decided one by one by processing and developing of three dimensions in the process of the full size drawing. Accordingly, these pieces are calculated by standard measure in this stage.

As a result of this work Material List of SD (⑧) is prepared and this includes all the elements for the estimation such as quantity summary table (by thickness and grade), number of large and small pieces, number of blocks and also welding length.

The drawing of SD preparation work (⑦) is the work that makes the drawings of SD (⑨) on the basis of SDM (⑤) by selecting and designating the standardized details such as splice arrangement prepare drawings of SD, common detailed figures etc., from the Book of Standardized Details. Also, the drawings of SD supplement SDM by expressing the structural details of welding standard, the arrangement of accessories and the detail of connections, which are not easy to be expressed only by text data.

3.2.2. Structural detail design.; SDD

SDD preparation (⑩ of Fig. 6) is the work to decide the structural details for the fabrication on the basis of SDM (⑤) which data can be generated by utilizing the general drawing systems and full size drawing system. In this process, the possible problems or errors in fabrication or erection stage such as the interference and execution of the members and components are checked and if there are some, they are corrected and reflected on the product model/completion (⑪). The drawings of SD are corrected at the same time. The corrected drawings of SD are drawings of SDD (⑬) and will be the final drawings after they are approved by owners.

Material List for estimation (⑧) is modified, in the case that the addition or modification are required as a result of SDD preparation work (⑩). This is the Material List of SDD (⑫) and the change order of the contract will be carried out based on this Material List as well as the drawings of SDD (⑬).

3.2.3. Preparation of fabrication data

Addition of camber data (⑭, Fig. 6) is to add fabrication camber to product model/completion (⑪) to generate the product model/fabrication. (⑮). At the same time the allowance should be considered such as the shrinkage by welding, procedure of assembling of pieces and welding methods etc., which depend on the know-how of each fabricator. Therefore the actual way for the preparation of fabrication data may differ fabricator by fabricator.

Specification of the product model/fabrication is the same as that of product model/completion. The product model/fabrication includes attributes of pieces such as procedure of assembling and welding data and all other fabrication related information as well as the allowance for shrinkage of welding and camber.

From this product model/fabrication, the drawing of each piece, processing control information and also various kinds of control sheets, Material List for fabrication and NC marking data for the fabrication are to be generated.

3.3. Product model

The characteristic of this system is adoption of the product model in the second half of the information flow as well as the introduction of text file data exchange in the first half.

Most fabricators have already experienced their own development of factory equipments with software for the latter part of the information flow (Takaku 1994, Takaky 1995, Iida 1997). Product model should be established according to their on experience and investment of factory equipment in past and may differ fabricator by fabricator. Therefore the fundamental and common thought is discussed here.

Product model, generally so called in the manufacturing industry is a database including data of form and shape of products, allowable range of error, material data, product constitution, process and control data of production. The data in product model can be utilized through all the life cycle of the product from planning, design, production, inspection and maintenance.

On the contrary the scope of the product model in this system is limited to cover mainly the data after the fabrication stage.

3.3.1. The necessity of the product model

The shop drawings of the conventional system still relies on the same principle as traditional full size drawing method in which the shape and form of the members and pieces of bridge components are generated as two dimensions referring to the basic skeleton in the design drawings. The data such as three-dimensional angle between members or pieces is lost in the process of these conventional full size drawings and the data must be added separately.

In the conventional method, assembled state is not visible as image and in the case of complex structures with many connections, skilled draft workers are still inevitable. On the contrary, product model makes it possible to express the form and shape in the assembled state of three dimensions as virtual image. Product model is diffusing rapidly in the fields of several production industries including an automobile.

In the fields of steel bridge superstructures the demand for the data of three dimension is rising according as the introduction of robotic machines with multi-joints (Fig. 7) (Takaku 1994) or NC trial assembling method. However, in the case of steel bridges, to transform the two dimensional data into three dimension is impossible because the bridge components include members and pieces with torsion or bending shapes in some cases. The fabrication data should be generated in three dimensions from the beginning.

Fig. 7 Welding robots with multi-joints in bridge factory

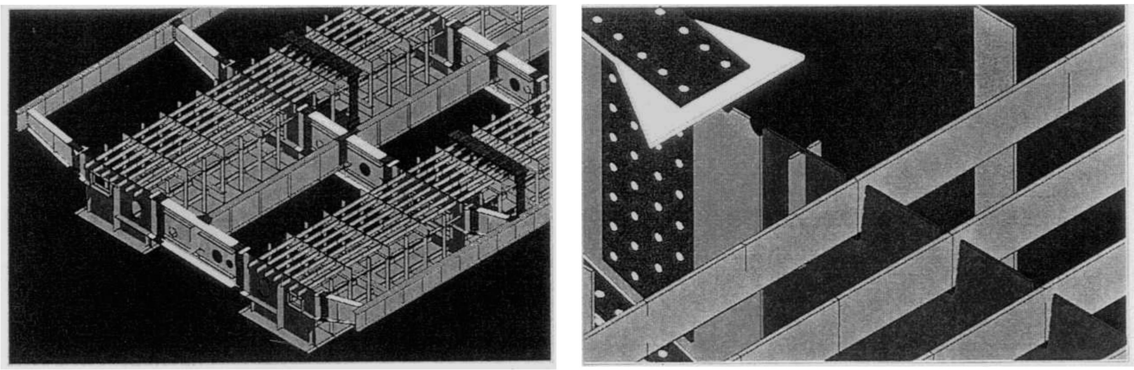


Fig. 8 The bird’s-eye view and the details of RC box girder by solid model

3.3.2. Effect of product model

Product model treats totally various attribute information as well as the data of shape and form which are required for the fabrication without recognizing the difference of bridge type. The product model supplies the production control data such as the data for the distribution and flow of products and fabrication data for components which change according as the fabrication stage.

Also the product model supplies the data to the new equipments such as a multi-joints welding robot or painting robot and to the simulation program for the check of the interference and execution of members in complex structures and also to the system of NC trial assembling.

For the check of the interference and execution of members either one or the combination of the models of Wire Flame, Surface or Solid is applied according to the purpose of the check.

Wire Frame model is suited to the expression of the skeleton of steel bridge structures and responsiveness is good because the data volume is relatively small due to the simple expression. In the case of the check of shape of members and pieces with thickness of steel plates, special attention should be paid in the same way as Surface Model because of the voluminous data.

Fig. 8 shows the bird's-eye view and the details of RC box girder displaying with shade by Solid Model. Fig. 9 shows the bird’s-eye view of plate girder by Wire Frame Model and Fig. 10 shows the

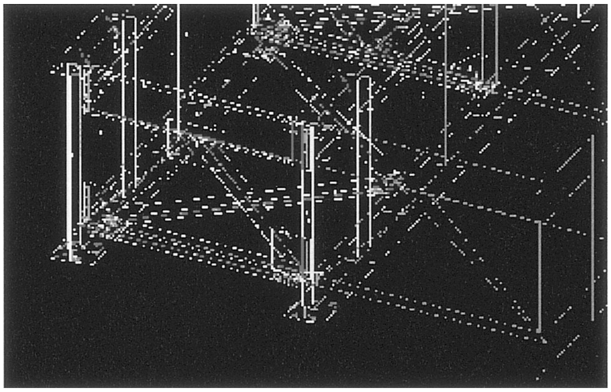


Fig. 9 The bird's-eye view of plate girder by wire frame model

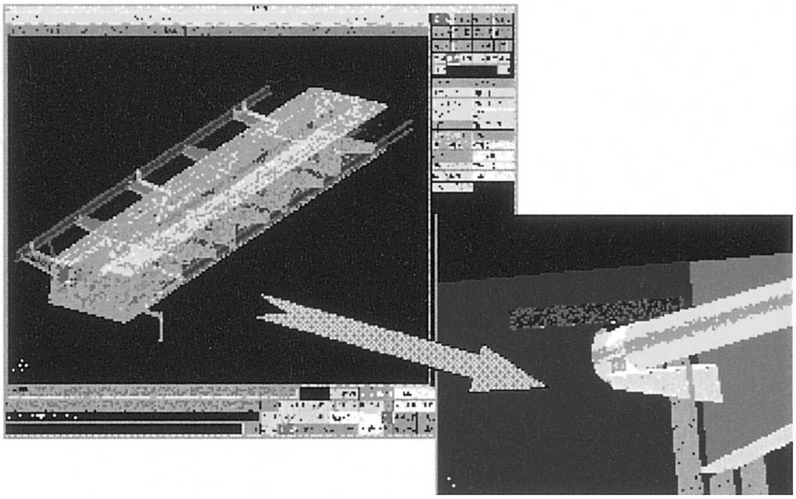


Fig. 10 The model for the interference checking

Table 6 The contents of a standard product model

Items	Contents
Member data	- Piece mark, grade, thickness, surface coadting - Position, methods, schedule - Scope (sub-contractors) - Two dimensional shape (Before fabrication) - Three dimensional shape, (After fabrication) - Attributes (holes, bending, grinding)
Block, half block data	- Block mark, transportation mark - Composition of members, components - Assembling methods, schedule
Connection data	- Kind of connections (Bolts/Welding) - Connection members, block, schedules

model for the interference checking.

Once the product model is established valuable control data will be supplied through all the process from planning of fabrication, full size drawing to inspection, transportation and the erection at site.

In future, it becomes possible to supply the virtual image such as color of paintings, packages and loading image on track for transportation, locus of the transportation truck on narrow road, image of the temporary stockyard for the bridge components and equipments for erection, movement and revolution of crane and bolting work image at the splice of members. The contents of a standard product model for the steel bridge superstructure are shown in Table 6.

4. The way of the inspection of the full size drawing and product

The steel bridge fabrication is not just procurement of goods but service and treated as construction works to be carried out in accordance with the contract of public works. Therefore the procedure of the inspection and the approval by the owners has an important meaning in the contract procedures. However, the method and the contents of the inspection should be changed according to the development of the system.

The way of the inspection should be as follows in the new fabrication information system.

4.1. Full size drawing inspection

The original purpose of the full size drawing inspection was to check the drawings, which were drawn on the floor in full size according to the design drawings supplied by owners as a contract document. The process of making the full size drawing was also the process of the checking of the supplied design drawings by contractors.

The original purpose of the full size drawing inspection is basically same as that of this new system. It is to be checked and judged by owner if the transformation to the fabrication data has been correctly carried out from the contract document.

In the stage immediately before the start of fabrication the product model/completion and the product model/fabrication have been generated and the forms and shapes of all the members and pieces have been decided including drain, inspection walkway, temporary stiffening pieces for erections. Therefore it becomes possible for owneris inspectors to grasp the image of the assembled state as well as the fundamental skeleton and the shapes of the each member.

In the new system the attribute of members such as the grade of materials and the shape of welding grooves can be checked by the teaching function of steel bridge product modeler. Furthermore, the advisability of the condition of welding workspace, installation of members, condition of bolting work, the interference of members in assembling in the factory or construction site can be checked by visual and/or numerical way, if necessary.

As for the method of the inspection, it will be carried out in the same way as before using the documents output from the product model. Generally the inspection covers the checking of the skeleton, the comparison between the detailed numerical values of the product model and SDM or drawings of SD, main measured values and fabrication camber. All the necessary documents for the inspection are prepared based on the specification standardized with STEP/AP202.

The figure of each member housed in the product model can be shown in three dimensions on the display from the suitable direction and in suitable range by cricking the member on the structural model on the display.

The assembled state of the panels and blocks are also shown on the display in three dimensions with major sizes in the same way as members or pieces. Members, pieces and assembled state are checked on the display or printed drawings. The whole structure is checked by the bird's-eye view or perspective from optional viewpoints on the display.

Members interrupting the view are deleted partially or drawn as half see through and the viewpoints can be moved as if inspectors walk around inside the structures. In this process of the "walking", optional points can be measured for check.

In the case of joint venture contract and the structure is fabricated more than two fabricators, the inspection of the boundary parts are carried out in duplicate by exchanging the standardized product model between the fabricators.

As described above, the full size drawing inspection actually becomes "product model inspection" according to the additional function by product model.

4.2. Final Inspection (Product inspection)

Final inspection at factory, generally called product inspection is divided to a member inspection and trial assembling inspection. The purpose of these inspections is to check and judge the quality of members and assembled members compared with the approved standard in the product model.

In the case of join venture contract, the inspection of the boundary parts is carried out by exchanging data mutually and in some cases, actual splice plates or adjacent blocks are also exchanged.

The results of the measurement of members, the appearance inspection, X-ray inspection of welded parts, ultrasonic waves inspection are digitalized and housed in the product model. Product model also houses the standard values to check the members and assembled state at optional points.

The NC machines and robots are operated by the data from the product model. The quality of the products depends on the accuracy of the estimation for the allowance of cutting and welding shrinkage and assembling. Therefore by accumulating the results of inspection for fabrication in product model, error can be minimized combining with other conditions. That is another aspect of the effect of the product model for quality control.

5. Consideration and subjects in future

5.1. Evaluation of the drawing of SD

The drawing of SD in this system is developed for the purpose of the construction CALS. And detail design information data is also exchanged in the form of text data of SDM

The conventional design drawings are drawings suitable for human eye and not for computer. In the computer oriented new system, another drawings suitable for computer eye are required. This is why the drawing of SD is introduced in this system.

Since the volume of the data on the drawing of SD decreases very much compared with the conventional ones, the data exchange between consultant firms and owners, owners and fabricators becomes efficient greatly due to the "light data".

However, the conventional drawings are the accumulation of knowledge for a long time and have a lot of merit after the completion of the structure for the purpose of the maintenance. The drawing of SD should be considered again from another point of view in future.

Data exchange of drawings of SD will be carried out by the data format (ISO/STEP-AP202) as mentioned before. However, according as the development of fabrication lines and equipments in factory far more three dimensional data will be directly needed. Therefore in near future the product model conformed to ISO/STEP-AP203 by advancing this system should be in target for the next research and development.

5.2. Data exchange by the product model

By the adoption of the product model the data needed for the fabrication can be output integrative way. When the data exchange of the product model becomes smoothly in future, the value for the utility of the product model will rise furthermore, which will make it possible to share the information of the life cycle of the steel bridge electronically and systematically. And this will result the avoidance of the risk for the error of information transmission, omission of useless work such as duplicated data input and the checking work, promotion of the accumulation of data and its application in comparison with data exchange by drawings and documents. The system proposed in this paper has the possibility to be advanced to the product model exchange in near future.

The following merit can be obtained by the adoption of the product model exchange in the construction of steel bridge superstructure.

- The data is preserved for long time as common property, which enables the management for the life cycle of the steel bridge.
- The data exchange and mutual inspection of the boundary part in the case of join venture contract are carried out easily.
- Sharing the fabrication by more than one fabricator becomes easy.
- The useful information for the erection can be supplied
- The elaborate information exchange with other industry or owners can be realized.

5.3. Linkage to the data flow following the fabrication stage

For the purpose of the utilization of the product model generated in the latter part of this system, the study for the linkage to the down flow such as erection at site and maintenance after completion is important. This part is not mentioned in this study but it is worthwhile to study for the development of Construction CALS/EC in near future.

References

Akeno, K. (1997), “The action program on the construction CALS/EC”, *Bridge & Foundation*, Kenstsu-Tosho Co., **31**, 180-182.

Hara, S. (1999), “The study on construction CALS/EC by japan association of steel bridge construction”, *Bridge & City Project*, **35**, 51-55.

Iida, M., Ishimura, H., Tanabe, N. and Ishikawa, N. (1997), “Development of new computer aided fabrication system for steel bridges”, *Proceedings of Yokogawa Bridge Co*., **26**, 89-99.

Isohata, H. (1998), “Construction CALS/EC for steel bridge superstructures”, *Bridge & City Project*, **34**, 23-26.

JASBC (2000), “Construction CALS by Japan association of steel bridge”, *Niji-Bashi*, *Journal of JASBC*, 69-75.

Mikami, I., Tanaka, S., Kuroda, M. and Murata, S. (1999), “CALS-oriented experts system for supporting detail design of steel highway bridges”, *Proceedings of JSCE*, **623**/VI-4, 190-199.

SCADEC (1999), Standard CAD Date Exchange Development Consortium meeting reference, “Introduction of software”, by No. 3 Working Grope.
Shimazu, S. (1998), Tackling to the Construction CALS/ECÅA*Kensetugyo-Shinkou*, Kensetu-Kikin, **276**, 2-12.
Shimazu, S. (1999), Status Quo of Construction CALS/EC, *Bridge & City Project*, **35**, 73-76.
Takaku, T. and Ogaya, S. (1994), “Bridge factory innovation tsu works - bridge fabrication using high speed rotation arc welding robots”, *Proceedings of Steel Structures*, **1**(4), 65-80.
Takaku, T., Fujimura, K. and Ogaya, S. (1994), “Bridge factory innovation”, *Structural Engineering International* 1/94 IABSE, 34-36.
Takaku, T., Watanabe, T., Yoshikai, T. and Haga, K. (1985), “Integrated CAM system for I-girder steel bridges”, *Proceedings of NKK Corp.*, **109**, 50-55.
Takaku, T. and Ogaya, S. (1995), “Bridge design and factory innovation”, *Journal of JSCE*, **80**, Feb. 1995.

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