# DEVELOPMENT OF A KNOWLEDGE-BASED EXPERT SYSTEM FOR SELECTION OF STEEL BRIDGE ERECTION METHOD

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The present paper aims to introduce a newly developed expert system which is capable not only of various inferences and judgements for the selection of erection method in steel bridges with a resultant certainty factor but also of output of consultation results on selection process by using the "*How*" and "*Why*" functions. For the construction of the knowledge base including the subjective information related to the condition of bridge site, a selection process model and *IF-THEN* rules that can capture most of the available information about selection of erection method in steel bridges were established through few interviews with a domain expert. Finally, some analysis examples for the completed steel bridges are presented so as to demonstrate the suitability of this expert system.

***Key Words:*** *steel bridge, erection method, knowledge-based expert system*

## 1. INTRODUCTION

Since there are a number of in-situ erection methods in construction of steel bridges such as truck crane-bent erection method, cable erection method, etc., the selection of erection method is usually performed based on a combination of both the objective and subjective judgements of expert in the related bridge site. Then, the necessity of a practical selection system (such as a knowledge-based system) of erection method has been pointed out at both preliminary and detail design stages for a steel bridges.

Expert systems, a form of application of artificial intelligence, have been attracting great attention, and some are said to be reaching a practicable stage [1]. Expert systems have lots of advantages such as handing over knowledge and experience of engineering experts to users in an explicit and reliable format, and expanding services in various fields even when only a limited number of engineering experts are available for problem solution. At present, however, expert systems have yet to be put to practical use on a full scale in the field of civil engineering. In fact, as development of expert systems proceeds, one new problem surfaces after another [2].

On the other hand, it is becoming important to select the most efficient erection method at bridge planning and design stages now that bridges are becoming bigger and more complex, providing greater multi-functionality, and being erected in more diverse locations. The erection method selection process requires substantial knowledge and experience based on the information on the type, scale and erection location of the bridge, and needs to rely on the experience and intuition of skilled engineers with many respects. The

Table 1 List of erection methods covered by the expert system.

| |
|---|
| Truck crane bent erection method |
| Truck crane large block erection method |
| Truck crane bent/lateral transfer erection method |
| Truck crane large block/lateral transfer erection method |
| Cable crane bent erection method |
| Cable erection direct lifting method |
| Floating crane bent erection method |
| Floating crane large block erection method |
| Launching erection method |
| Erection girder launching method |
| Turning method |
| Deck barge large block erection method |

Table 2 Erection method selection factors.

| Item | Factor |
|---|---|
| Erection point | Topography |
| | Intersecting objects under the bridge |
| Surrounding conditions | Utilization of space under girder |
| | Work yard |
| | Obstacles in the air |
| | Member carry-in route |
| Main characteristics of the bridge | Bridge type |
| | Safety during erection |
| Erection machinery and material | Availability of necessary machinery and material |

need for systematizing the process, using new technologies such as expert systems or the like is, therefore, now being recognized.

In order to meet the above need, an attempt was made in this study to develop an expert system for selection of erection method in steel bridges for such bridge types as plate girder and box-girder bridges. This paper describes how the system was built, how inference results were verified based on sample data, and how its applicability was increased.

## 2. DEVELOPING EXPERT SYSTEM

Expert systems consist of a knowledge base which represents acquired knowledge in a certain format, an inference engine which makes inferences based on the knowledge base, and a user interface which interacts with the user and presents inference results. In building our system, the expert system shell which is called *Dai-so-gen/TB for Windows* [3] was used.

Expert shells, a tool developed for building an expert system, clear the knowledge base and present knowledge acquisition, inference and user interface facilities. Knowledge was systematically stored in our knowledge base through reference to various literature, in-depth analysis of originally collected erection method selection examples, and interviews with experts on many occasions.

Knowledge was represented based on *IF* (an antecedent part)/*THEN*(a consequent part) production rules and by using tables listing multiple common rules [4]. A certainty factor was used to express the degree of certainty in particular knowledge. The certainty factor determines the certainty of a conclusion on a range from +1.0 to -1.0. Total belief is represented by +1.0, and total disbelief by -1.0. Uncertainty levels between these two extremes range from +0.9 to -0.9.

## 3. SYSTEM DESCRIPTION

As bridge erection methods to be selected under the expert system, twelve methods are listed as shown in Table 1 because two types of steel bridges - plate girder and box-girder bridges - have been chosen for our consideration [5]. If the condition makes it difficult to select any specific method, combined use with other methods will be output as a result of inference.

In general, the key conditions for selecting an erection method are safe and reliable implementation, economy and scheduled completion [6]. In order to meet such conditions, comprehensive judgement should be made as to the items listed in Table 2 such as erection point, surrounding conditions, main characteristics of the bridge and erection machinery and material. In developing the expert system, the process of reviewing these factors was defined in the "Erection method selection flowchart" shown in Figure 1 by making a detailed analysis of originally collected erection method selection examples and having repeated interviews with domain experts. The flowchart was then used as a basis for systematizing knowledge.

The items shown at branch points in the flowchart such as (1)Erection point and (2) Condition under girder, etc. are factors for selecting erection methods, listed in Table 2. A total of 18 factors are specified as

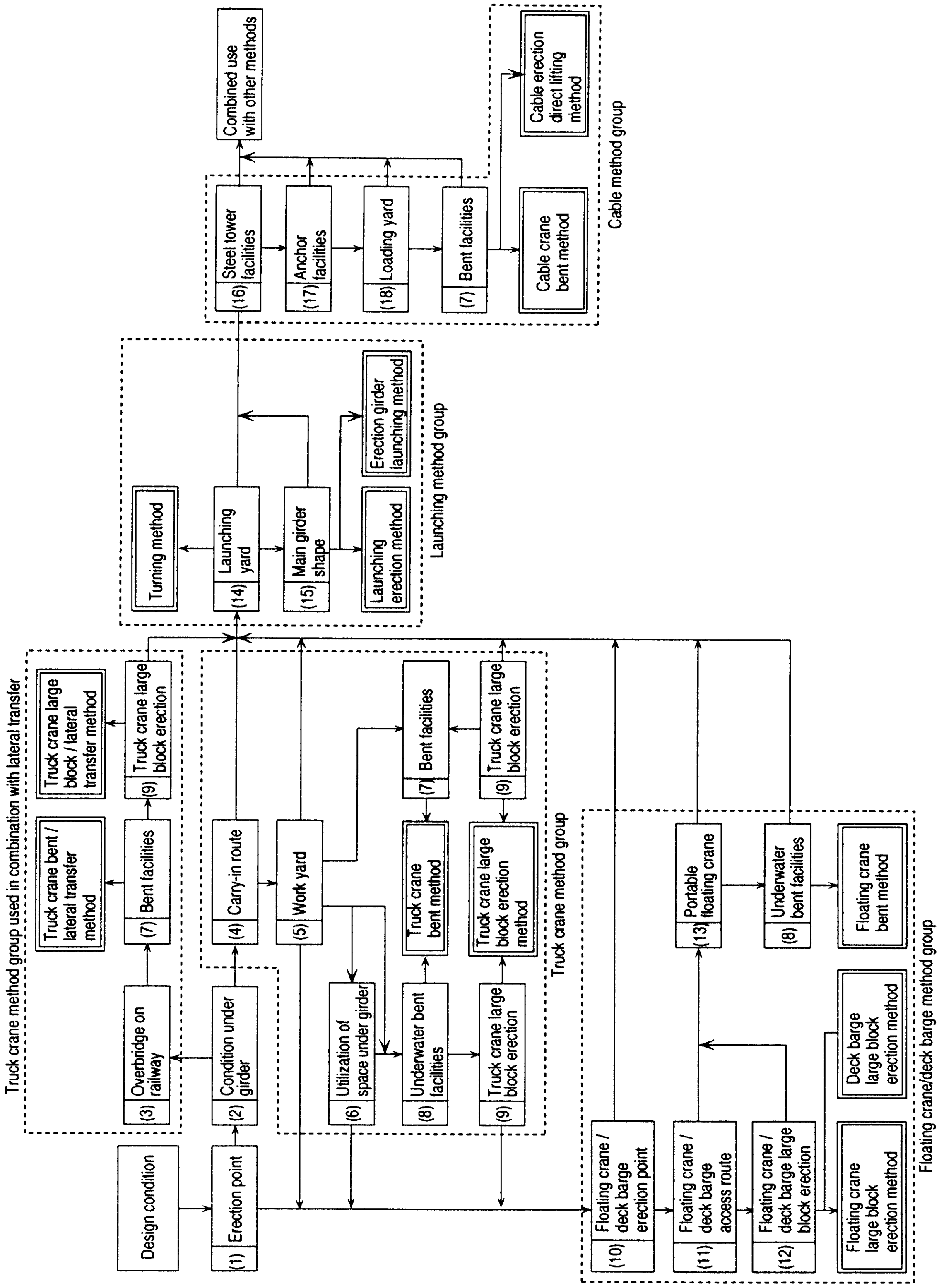



Figure 1 Erection method selection flowchart.

Table 3 Confirmation items and options for the review item (7) bent facilities -an example.

| Review item | Confirmation item | Options | | |
|---|---|---|---|---|
| | | (1) | (2) | (3) |
| (6) Bent facilities | 1. Construction vehicles' access to and installation at the point where bent is set up | Possible | Preparation required | Impossible |
| | 2. Topography at the point where bent is installed | Flatland | Grading required | Grading impossible |
| | 3. Bent foundation | Sleeper and steel sole plates | Concrete | Pile foundation |
| | 4. Obstacles such as existing objects and water channels at the point where bent is installed | None | Transfer/removal possible | Transfer/removal impossible |
| | 5. Height of the bent | $H \leqq 10\text{m}$ | $10\text{m} < H \leqq 30\text{m}$ | $30\text{m} < H$ |

Table 4 List of erection method groups and corresponding erection methods.

| Erection method group | Erection method |
|---|---|
| Truck crane method group | Truck crane bent erection method |
| | Truck crane large block erection method |
| Floating crane/deck barge method group | Floating crane bent erection method |
| | Floating crane large block erection method |
| | Deck barge large block erection method |
| Truck crane method group used in combination with lateral transfer | Truck crane bent/lateral transfer method |
| | Truck crane large block/lateral transfer method |
| Launching method group | Launching erection method |
| | Erection girder launching method |
| | Turning method |
| Cable method group | Cable crane bent method |
| | Cable erection direct lifting method |

Table 5 Example of evaluation conditions for a review item.

| Evaluation rank | Evaluation condition |
|---|---|
| (A) | "Reasonable" for all confirmation items |
| | "Slightly reasonable" for one confirmation item, and "reasonable" for all of the other items |
| (B) | Evaluation rank is other than A, C or D. |
| (C) | "Slightly reasonable" for more than half of the confirmation items. No item is regarded "unreasonable". |
| (D) | At least one of the confirmation items is regarded "unreasonable". |

review items which are subjected to evaluation with respect to confirmation items. For each confirmation item, two to five options are assigned according to its characteristics. For example, (7) Bent facilities are evaluated in terms of five confirmation items as shown in Table 3.

In inference under the expert system, the process from user input (the user selects an appropriate option) to selection of an erection method is divided hierarchically into three stages of evaluation from confirmation and review of factors to identification of the erection method group, and to selection of the erection method. The system is designed so as to reach final certainty factor for the selected erection method by summing up certainty factor obtained at each stage. All of the twelve erection methods are classified into five groups based on the erection machinery and material involved, namely, truck crane method group, floating crane/deck barge method group, truck crane method group used in combination with lateral transfer, launching method group, and cable method group shown in Table 4.

Review items are evaluated according to user input with respect to multiple confirmation items, and ranked at one of the four grades based on the evaluation conditions shown in Table 5.

Table 6 Inference pattern identification for erection point and condition under girder.

| Inference pattern | Erection point | Condition under girder | Erection method group to be inferred |
|---|---|---|---|
| 1 | On the ground | Flatland<br>Road<br>River (high channel) | Truck crane method group<br>Launching method group<br>Cable method group |
| 2 | On the ground | Railway | Truck crane method group used in combination with lateral transfer<br>Launching method group |
| 3 | On the ground | River (running water), lake and marsh, and pond | Truck crane method group<br>Floating crane/deck barge method group<br>Launching method group<br>Cable method group |
| 4 | Offshore | – | Floating crane/deck barge method group<br>Launching method group<br>Cable method group |

Table 7 Classification of review items.

| Review items for erection method group | Erection method group | Review items for erection method | Erection method |
|---|---|---|---|
| (4) Carry-in route<br>(5) Work yard<br>(6) Utilization under girder | Truck crane method group | (7) Bent facilities<br>(8) Underwater bent facilities | Truck crane bent erection method |
| | | (9) Truck crane large block erection | Truck crane large block erection method |
| (10) Floating crane/deck barge erection point<br>(11) Floating crane/deck barge access route | Floating crane/deck barge method group | (12) Floating crane/deck barge large block erection | Floating crane large block erection method |
| | | | Deck barge large block erection method |
| (13) Portable Floating crane | | (8) Underwater bent facilities | Floating crane bent erection method |
| (3) Overbridge on railway | Truck crane method group used in combination with lateral transfer | (7) Bent facilities | Truck crane bent/lateral transfer method |
| | | (9) Truck crane large block erection | Truck crane large block/lateral transfer method |
| (14) Launching yard | Launching method group | (14) Launching yard | Turning method |
| | | (15) Main girder shape | Launching erection method |
| | | | Erection girder launching method |
| (16) Steel tower facilities<br>(17) Anchor facilities<br>(18) Loading yard | Cable erection method group | (7) Bent facilities | Cable crane bent erection method |
| | | (8) Underwater bent facilities | Cable erection direct lifting method |

Of the review items, (1) Erection point and (2) Condition under girder are reviewed to determine any of the inference patterns listed in Table 6 because the erection method group for which inference is made can be identified. All of the remaining 16 items, (3) Overbridge or railway through (18)Loading yard, are classified into those to be evaluated for identifying the erection method group and those to be evaluated for the erection method as shown in Table 7.

Certainty factors given to the erection method groups according to the review item for evaluation rank have been set as shown in Table 8. Certainty factors here need to be constant regardless of the number of the review items. If evaluation is made with respect to more than one review item, certainty factor is calculated based on the combined total of items so that it may equal that based on one review item.

Evaluation with respect to review items should be made for all the erection method groups. Therefore, appropriate certainty factors have been given even to the erection groups which are inferred before or after the one inferred based on review items.

## 4. SYSTEM ASSESSMENT AND IMPROVEMENT IN SYSTEM APPLICABILITY

### (1) System verification with sample data

In order to verify the reliability of the expert system, erection methods were actually selected (inferences were made) under the system for eleven examples out of those originally collected. The inference results are as listed in Table 9. For nine of the examples, the erection method actually adopted was rated highest under the system (hit rate stands at 82%). As the bridge seems to have been erected under unique condition in the two cases (case 7 and case

Table 8 Sample certainties for erection method group with respect to review items.

| Rating | Number of review items | Erection method group | | |
|---|---|---|---|---|
| | | X | Y | Z |
| (A) | 1 | -0.10 | 0.90 | -0.70 |
| | 2 | -0.05 | 0.69 | -0.45 |
| | 3 | -0.04 | 0.54 | -0.33 |
| (B) | 1 | -0.05 | 0.60 | -0.60 |
| | 2 | -0.03 | 0.37 | -0.37 |
| | 3 | -0.02 | 0.26 | -0.26 |
| (C) | 1 | 0.05 | 0.30 | 0.05 |
| | 2 | 0.03 | 0.17 | 0.03 |
| | 3 | 0.02 | 0.12 | 0.02 |
| (D) | 1 | 0.01 | -1.00 | 0.01 |
| | 2 | 0.01 | -1.00 | 0.01 |
| | 3 | 0.01 | -1.00 | 0.01 |

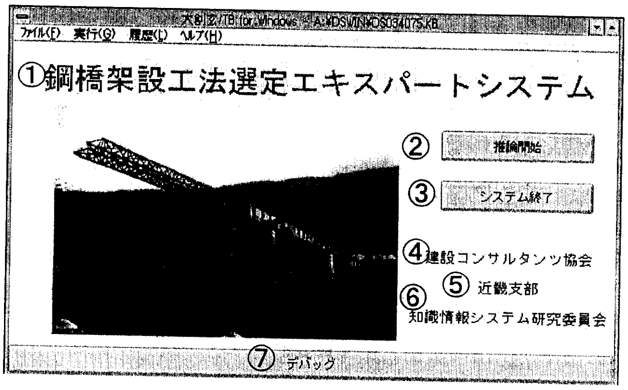
Note
X: Erection method group inferred before erection method group Y
Y: Erection method group corresponding to the review item
Z: Erection method group inferred after erection method group Y

Table 9 Verification of inference results with sample data.

| Sample data | Inference results | | Adopted erection method |
|---|---|---|---|
| | Erection method | Certainty factor | |
| Case 1 (Flatland) | Truck crane bent erection method | 0.80 | Truck crane bent erection method |
| | Truck crane large block erection method | 0.75 | |
| | Launching erection method | 0.63 | |
| | Erection girder launching method | 0.42 | |
| Case 2 (Running water) | Cable crane bent erection method | 0.81 | Cable crane bent erection method |
| Case 3 (Running water) | Truck crane bent erection method | 0.68 | Truck crane bent erection method |
| Case 4 (Railway) | Launching erection method | 0.81 | Launching erection method |
| | Erection girder launching method | 0.54 | |
| Case 5 (Running water) | Floating crane bent erection method | 0.39 | Floating crane bent erection method |
| | Truck crane bent erection method | 0.37 | |
| | Floating crane large block erection method | 0.20 | |
| Case 6 (Road) | Launching erection method | 0.58 | Launching erection method |
| | Truck crane bent erection method | 0.56 | |
| | Erection girder launching method | 0.39 | |
| Case 7 (Railway) | In combination with other erection method | 1.00 | Turning method |
| Case 8 (Flatland) | Cable crane bent erection method | 0.37 | Cable crane bent erection method |
| Case 9 (Running water) | Cable crane bent erection method | 0.42 | Cable crane bent erection method |
| | Cable erection direct lifting method | 0.21 | |
| Case 10 (Flatland) | Erection girder launching method | 0.84 | Launching erection |
| Case 11 (High channel) | Truck crane bent erection method | 0.54 | Truck crane bent erection method |

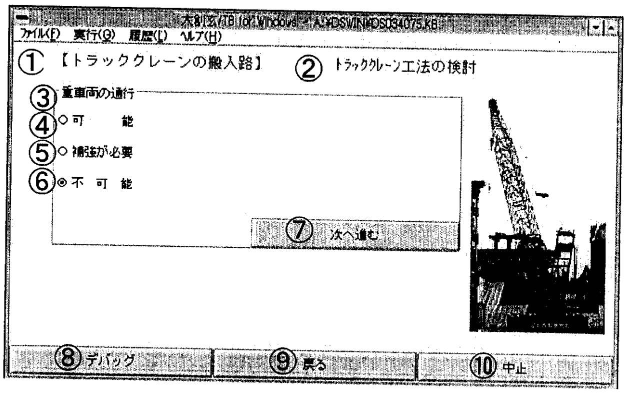
Table 10 Verification of inference results at an actual erection site.

| Condition under girder | Inference results | | Adopted erection method |
|---|---|---|---|
| | Erection method | Certainty factor | |
| High channel | Truck crane bent erection method | 0.68 | Truck crane bent erection method |
| | Launching erection method | 0.59 | |
| | Erection girder launching method | 0.39 | |
| Running water | Floating crane bent erection method | 0.40 | |
| | Truck crane bent erection method | 0.39 | |
| | Launching erection method | 0.20 | |



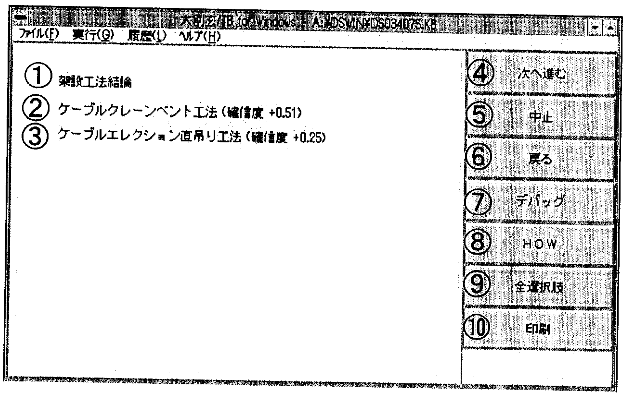

① Expert system for selecting steel bridge erection method
② Start inference
③ Close system
④ Japan Civil Engineering Consultants Association
⑤ Kinki Branch
⑥ Knowledge information processing system study committee
⑦ Debug

Figure 2 Startup screen of the expert system.



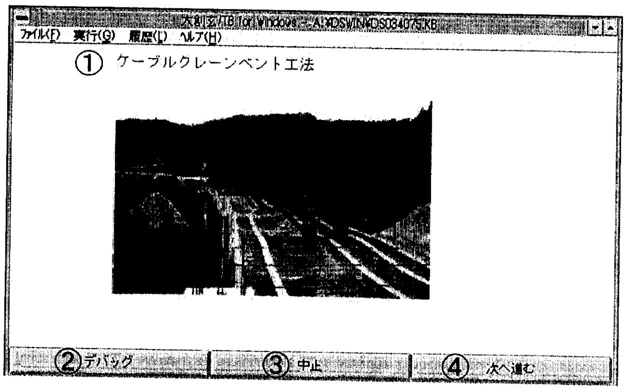

① Truck crane carry-in route
② Review of truck crane method
③ Possibility of heavy vehicles approach
④ Possible
⑤ Reinforcement required
⑥ Impossible
⑦ Next
⑧ Debug
⑨ Return
⑩ Cancel

Figure 3 Sample input screen.




① Erection method inferred
② Cable crane bent method (certainty factor: +0.51)
③ Cable erection direct lifting method (certainty factor: +0.25)
④ Next
⑤ Cancel
⑥ Return
⑦ Debug
⑧ HOW
⑨ All Selection
⑩ Print out

Figure 4 Sample screen for inference results output.




① Cable crane bent method
② Debug
③ Cancel
④ Next

Figure 5 Sample image display of selected erection method.

10) where the inference result did not match the actual method adopted, the system is considered highly reliable.

In addition, the system was run live at an actual erection site to select the erection method while confirming on-site conditions through discussions with the person in charge of the site. At this site, a three-span continuous box girder bridge crossing a large river having high channel and running water sections was being erected in the truck crane bent erection method. In the running water section, a construction stage (pier) was built for carrying in bridge members and cranes.

The results of selection under the system are as shown in Table 10. Where there was a high channel under girder, truck crane bent erection method was ranked highest, and where there was running water under girder, floating crane bent erection method earned the highest mark. Even where there was running water, crane bent erection method which was actually adopted was ranked second, which means that there was only a slight variance in certainty factor.

Interviews with the experts who were involved in the above mentioned selection of erection methods resulted in the following comments.

1) Floating crane bent erection method selected for running water section has a little possibility of being adopted because the portable floating crane used in this method can bear only a relatively small weight and cannot bear the weight of the members used at this erection site.
2) Launching erection method selected for either of the conditions under girder has a little possibility of being adopted in view of key factors involved such as the length of span and the weight of erection members.
3) Even when conditions vary under girder, adoption of one and the same method throughout is often more effective in terms of erection cost.

Of the above comments, 1) and 2) indicate that the weight of erection members is a key factor in determining the erection equipment, and 3) refers to the need to consider total cost of erection even when conditions vary under girder. These points turned out to have caused variances in inference results. Studies will be continued on these matters.

### (2) System applicability

Input/output screens used in systems operation should be designed so that the system may be highly friendly to the user. For this reason, image data such as pictures and photographs have been incorporated into the screen for reference in order to increase operability and usability. Typical screens used in this system are shown in Figures 2 through 5. Step-by-step data input, while referring to base design conditions and erection plan charts, in the stage of base design or detailed design for bridges makes it possible to easily present erection methods to be selected.

## 5. CONCLUSIONS

The major results produced in this study can be summarized as follows.

1) Analyses of existing erection examples and repeated interviews with experts resulted in the development of a highly reliable knowledge base.
2) Hierarchical inference process provides for easy addition of pieces of knowledge and for correction of certainty factors.
3) The system has been made unique by placing on input/output screens questions or the like as easy-to-understand image data.
4) The system has proved highly practicable as verification with large amount of sample data resulted in a relatively reliable hit rate of more than 80%.

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# 鋼橋架設工法選定エキスパートシステムの開発

宮本　文穂・小西　日出幸・中村　秀明

鋼橋架設工法の選定過程においては、橋梁形式、橋梁規模、架設地点の情報などに基づく多くの知識や経験が必要であり、熟練技術者の経験や勘に頼らざるを得ない部分が多く見受けられ、エキスパートシステムなどの手法を適用したシステム化の必要性が認識され始めてきている。
本研究は、このようなニーズに応えるために、橋梁形式の中で鋼橋の鈑桁橋および箱桁橋を対象とする「鋼橋架設工法選定エキスパートシステム」の開発を試みたものであり、その基本的な構築過程とサンプルデータによる推論結果の検証および実用性の向上について報告するものである。