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Practical System for Type Selection of Bridge Crossing River

Système pratique pour le choix du type de ponts

Praktisches System zur Typenwahl einer Flussbrücke

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SUMMARY

The authors have developed an expert system of type selection of superstructure and substructure which uses integrated knowledge of expert designers and rules from specifications in Japan as the knowledge base. The expert system adopts fuzzy set theory to express the ambiguity of design data, and utilizes online connection between workstation and host-computer to improve accuracy of substructure cost evaluation. In the conclusion, it is possible to select the appropriate type and to considerably reduce design work time by using this system.

RESUME

Les auteurs ont mis au point un système expert pour le choix de la superstructure et de l'infrastructure des ponts sur cours d'eau utilisant comme base de connaissance les acquis des concepteurs spécialisés et les réglement des normes japonaises. Ce système expert adopte la théorie du sous-ensemble flou pour exprimer l'ambiguité des données de dimensionnement et utilise une liaison directe entre les stations de travail et un ordinateur central afin d'augmenter la précision de l'évaluation des coûts de l'infrastructure. En conclusion, il est possible de sélectionner un type de structure approprié et de réduire considérablement le temps de travail apporté à la conception en utilisant ce système.

ZUSAMMENFASSUNG

Von den Autoren wurde ein Expertensystem zur Typenwahl des Ober- und Unterbaus entwikkelt, das sowohl auf das integrierte Wissen der Expertenentwickler als auch auf die japanischen Normenvorschriften als Kenntnisbasis gestützt ist. Das Expertensystem verwendet die Theorie der unscharfen Menge, um die Unbestimmtheit der Konstruktionsdaten auszudrücken und benutzt die Online-Verbindung zwischen Arbeitsplatz und Host-Rechner, um die Genauigkeit der Unterstruktur-Kostenauswertung zu verbessern. Mit diesem System können ein geeigneter Typ gewählt und die Entwurfskosten erheblich gesenkt werden.

1. INTRODUCTION

Selection of a bridge superstructure and substructure is very important in the process from its design through to erection. Unless the designer has many years of experience and wealth of knowledge, it is difficult to select a type that is economically and serviceably satisfying. Moreover, design work time as well as efficiency of the selection and construction cost evaluation varies greatly depending on the experience of the designer. If designers use the integrated knowledge of expert designers, they can expect many merits. Hence, the authors have developed a system for basic design scheme of river crossing bridges as a practical application of the expert system.

Design conditions for superstructure and substructure of a bridge vary greatly depending on whether the bridge is to be located in a mountain area, urban region, across a river, and so on. A system applicable to all locations can become bulky and difficult to develop. On the other hand, river crossing bridges account for about half of all bridges constructed in Japan each year. The authors, therefore, limited the scope of the system to river crossing bridge. For river crossing bridges, the designer must take account of the River-Crossing Structure Law in Japan, making it especially difficult to decide a satisfactory span arrangement in accordance to the Law.

This system uses an expert shell (KEE) for easy development of the knowledge base and Lisp programming language. The development of this system took about one year by two expert designers from the design division and two knowledge engineers from research divison. The designer can easily input the data using keyboard and mouse while interacting with the system. Namely, the designer can understand what data should be input by watching the monitor. Presently, the designer can only use Japanese with this system in the actual design work, but an English version of the user-interface is under development, for design scheme of river crossing bridges in foreign projects, and educational purpose for foreign students studying in Japan.

The knowledge base used in the inference and selection process of this system are from standard rules given in the Specification for Highway bridges in Japan, some manuals, conventional rules based on the knowledge of expert designers, and the above-mentioned River-Crossing Structure Law. These conventional rules was created by trial and error in discussion manner between with knowledge engineers and expert designers. This system can be utilized with foreign specifications by replacing the Japanese specification with others.

Cost evaluation of superstructure and substructure can be easily calculated with this system. Not only the total construction cost of superstructure and substructure but separate construction costs, for example, fabrication, painting and transport for steel bridges, abutment and pier can be calculated. Moreover this system evaluates economy, erection workability, maintenance and running comfort as total assessment. Although the data in the knowledge base to calculate construction cost are revised at intervals of several years in Japan, the revision of these data can be easily performed.

In particular, the pile type selection process adopts fuzzy set theory to express the ambiguity of design data. In calculating pile construction cost, the use of the charts in manuals may cause some calculation error. In this system, the workstation (Nihon UNISYS Explore 2) and host-computer (Nihon UNISYS series 2200) are connected online so that this system can infer the cost of pile based on the results of analysis by the host-computer, thereby, improving the accuracy of construction cost evaluation.

This paper describes the outline and feature of this expert system and discusses an application example of actual design plan for comparison.

2. APPLICATION EXAMPLE AND ITS CONSIDERATIONS

Fig. 1 shows the type selection procedure for this system. Fig. 2 shows the input data with results obtained from this system. In which, span arrangement and bridge type combination obtained from the actual design plan under the same design condition are shown for comparison. In this case, the system provided 30 combinations (12 PC bridges, 18 steel bridges).

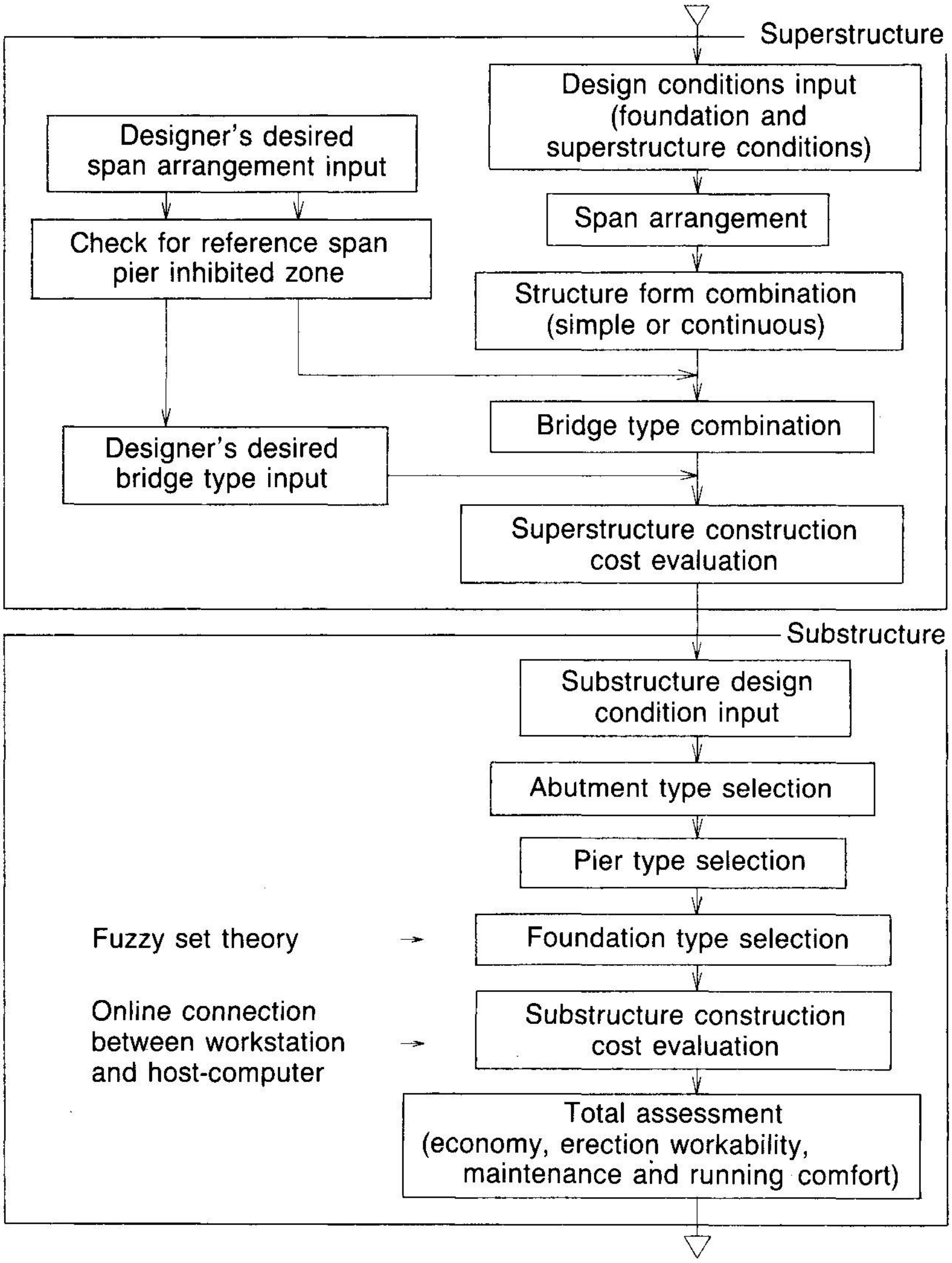

Fig. 1 Flow-chart of type selection procedure

Input data

BASIC DATA

Bridge length (m) : 307
River width (m) : 300
Skew angle (deg) : 80
Overall bridge width (m) : 10.75
Planned high water level (m) : 2
Hindrance to river improvement
: No
River discahrge (m^3/s) : 4350
Storm tide area : No
Backwater area : No
. . . .
. . . .

SUPERSTRUCTURE DATA

Effective bridge width (m) : 9.75
Restruction on girder hight
: No consider
Steel composite girder : Not used
. . . .
. . . .

SUBSTRUCTURE DATA

Horizontal seismic coefficient : 0.2
N-value of high river bed (left)
: approx. 30
N-value of low river bed : approx. 30
N-value of high river bed (right)
: approx. 30
Stage of gravel (mm) : from 5 to 10
Water depth at foundation work depth (m)
: approx. 4
Foundation work depth (m) : approx. 15
Vertical Load (span length (m))
: approx. 60
. . . .
. . . .

An example of results

① Actual design plan

Number of span	2	3	2
Span length (m)	2 @ 30.6 = 61.2	3 @ 60 = 180	2 @ 32.9 = 65.8
Bridge type	Continuous noncomposite steel I-girder	Continuous noncomposite steel box-girder	Continuous noncomposite steel I-girder

② This system

Number of span	2	3	2
Span length (m)	2 @ 30.4 = 60.8	3 @ 60.333 = 181	2 @ 32.6 = 65.2
Bridge type	Continuous noncomposite steel I-girder	Continuous noncomposite steel box-girder	Continuous noncomposite steel I-girder

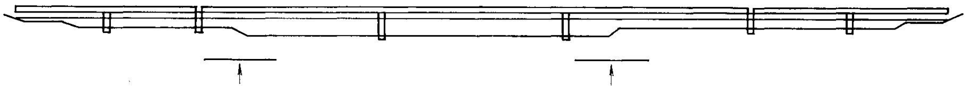

Fig. 2 Design conditions of actual plan and an example of results by this sytem

2.1 Type Selection of Superstructure

2.1.1 Span Arrangement

On completion of inputting data needed for type selection of superstructure, for example, topography, river width, river discharge, overall bridge width, bridge length, etc., the regulation of the River-Crossing Structure Law [1] (reference span length, pier inhibited zone, 5m relaxation regulation, exception to high river bed) are applied, and span arrangement is determined. These regulations are defined below and are used in the form of production rules in this system.

① Reference span length (minimum span length)
  This is to prevent any disturbance to the river flow caused by drifting objects such as trees due to floods.

② Pier inhibited zone
  This is to protect from anomalous scour around pier and obstruction to cross-selectional area of the river. So, pier inhibited zone is defined.

③ 5m relaxation regulation
  This is to relieve the condition that span length is much longer than reference span length. If the mean value of each length of all spans exceeds reference span length plus 5m, each span length can be made equal to or longer than reference span length minus 5m (in the case, the minimum reference span length is 30m).

④ Exception to high river bed
  When side span is located in the high river bed, if span length in the low river bed can be made longer, and if side span length can be made shorter, girder heights can be made lower. Thereby, raising of access road can be decreased.

Fig. 3 shows the rule-base of 5m relaxation regulation written in Japanese language.

All span arrangements obtained by the process above are displayed on the monitor screen. And the designer can remove undesirable span arrangements on his own judgement. The structural form (simple or continuous beam) with respect to span arrangements is determined. If the designer is not satisfied with any of the span arrangements proposed, this system allows the designer to input his desired span arrangement.

As shown in Fig. 2, these results from this system are approximately same span arrangements as the actual design plan. In actual design plan, expert designer moves pier minutely on his own judgement, taking into account appearance and other factors, for example, 1m or 1.5m off the boundary of pier inhibited zone. This problem can be solved by referring to the span arrangement results from this system and reinputting the span arrangement prefer by the designer.

基準径間長：Reference span length
上部工定数：Superstructure constants
橋長　　　：Bridge length
基本条件　：Basic conditions
最大径間数：Maximum number of spans

```
(IF (AND (AND (THE 基準径間長 OF 上部工定数 IS ? 基準径間長)
              (THE 橋長 OF 基本条件 IS ? 橋長)
              (THE 最大径間数 OF 上部工定数 IS ? 最大径間数))
         (AND (>= (/ ? 橋長  ? 最大径間数) (+ ? 基準径間長 5 ))
              (OR (AND (>= (- ? 基準径間長 5 ) 30)
                           (>= (/  ? 橋長 (+ ? 最大径間数 1 )) (-基準径間長 5 )))
                  (AND (< (- ? 基準径間長 5 ) 30)
                           (>= (/  ? 橋長 (+ ? 最大径間数 1 ) 30.0))))))
DO (PUT. VALUE  '上部工定数  '最大径間数 (+ ? 最大径間数 1 )))
```

Fig. 3 Rule-base of 5m relaxation regulation written in Japanese language

2.1.2 Combination of Bridge Type

A bridge type associated with each span arrangement is selected. Fig. 4 shows bridge types used in this system. First, applicable bridge types are assigned to a given span arrangement using design manuals [2], [3]. Combinations of bridge types are decreased with structural restrictions and heuristic rules of expert designers.

This system uses about 50 rules (about 150 rules in the entire system) to decrease the number of combinations of bridge types to about one-fifth. Some of these rules for bridge type selection are given as follows.

Structural restrictions
① Different bridge types (Steel bridge, PC bridge, Preflection beam bridge) cannot be used together.
② Simple composite box-girder and simple noncomposite box-girder cannot be combined.
③ Simple steel deck I-girder and simple steel deck box-girder cannot be combined.

Heuristic rules of expert designers
① Combining four or more bridge types is not feasible.
② When spans are arranged symmetrically, bridge types must also be arranged symmetrically.
③ Span length of box-girder bridge type must be longer than span length of I-girder bridge type.

As in the case of span arrangement, there is a routine that displays on the monitor all selected bridge types combinations, to allow the designer to further decrease them by eliminating inappropriate bridge types. Another routine allows the designer to select the desired bridge type by using menu.

As Fig. 2 shown, the combination of bridge types in this system is identical with the actual design plan.

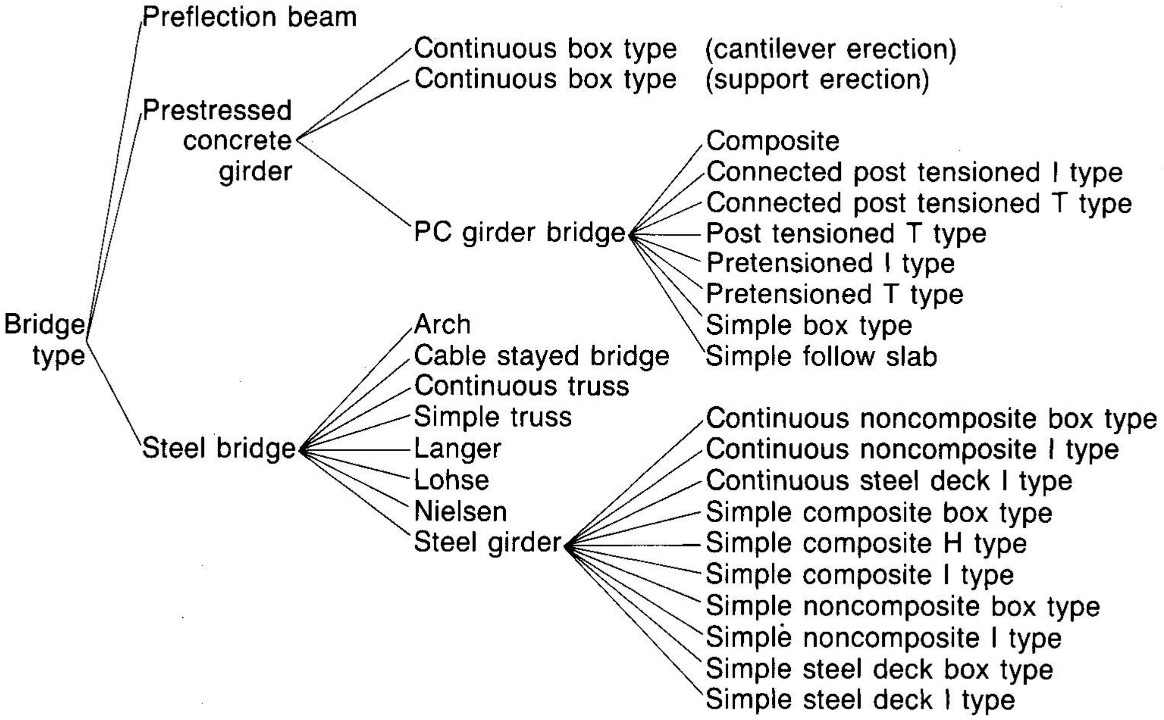

Fig. 4 Bridge types used in this system

2.1.3 Evaluation of Construction Cost

After selecting span arrangements and bridge types, the construction cost of superstructure is calculated for individual combination. The construction cost is calculated using charts information of design manuals [2], [3], [4].

Updating the knowledge base data to calculate construction cost of superstructure can be easily done by the designer in two ways as follows.
① Inputting the rise rate of construction cost for each bridge type.
② Reinputting the data for computerized charts of construction cost which are usually straight lines.

The evaluation is discussed in 2.2.3 with the construction cost of substructure.

2.2 Type Selection of Substructure

2.2.1 Type of Abutment and Pier

After the designer inputs data of the abutment shape, the system selects the type of abutment and pier according to table 1 that refers to the Design Data Book [2].

Using this table, the type of abutment and pier in this system is identical with the actual design plan.

2.2.2 Type of Foundation and Pile

Fig. 5 shows foundation types used in this system. The foundation type is usually selected by expert designer according to the foundation type selection table of the Specification for Highway Bridges [5].

However, the results of soil test are mere mean values of foundation work place, and these values have ambiguity. To give an example of "foundation work depth" in this table, when "foundation work depth" is 15 ~ 25m, sinso pile type is used frequently. On the other hand, when "foundation work depth" is 25 ~ 40m, sinso pile type is rarely used. If the result of soil test shows that "foundation work depth" is 25m without considering this ambiguity, selected pile type may be different from what expert designer will select.

Therefore, in this system, the authors applied fuzzy sets for pile type selection. As a result, a 1,200mm reverse pile is selected in this system. And this agrees with the pile type selected in the actual design plan. Thus, it seems that using fuzzy sets for pile selection is sufficiently practical.

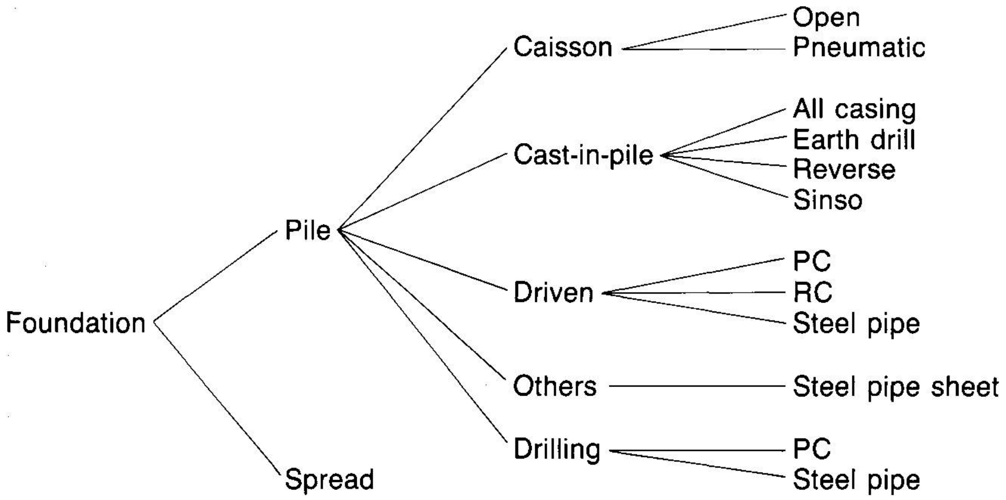

Fig. 5 Foundation types used in this system

2.2.3 Evaluation of Construction Cost

On completing type selection for abutment, pier and pile, the construction cost of substructure is calculated according to charts information of the Steel Bridge Design Planning Manual [3].

In calculating pile construction cost, the use of the charts in the Steel Bridge Design Planning Manual may cause some calculation error. In this system, therefore, the workstation and host-computer are connected online, and the pile construction cost is calculated based on the results of structural analysis by the host-computer.

Based on the result of pile type selection, the top three pile types are selected, and these pile diameters are changed. Table 2 shows all the possible pile types with the respect diameters. The stability and footing dimensions for abutments and piers and the required number of piles are calculated for each combination of pile type and diameter, using an existing structural analysis program at the host-computer. The input data for structural analysis are automatically created in the workstation and sent to the host-computer, then using the results of the analysis, each combination of pile construction costs is calculated as follows.

Pile construction cost =
the number of piles × pile length × pile construction unit cost

Finally, the pile type is selected as the most economical one. Similarly, the excavation and cofferdam cost can be calculated.

Updating the knowledge base data to calculate construction cost of substructure can be easily done by the designer in two ways as follows.
① Inputting the rise rate of construction cost for each abutment, pier and pile
② Reinputting the data for computerized charts of construction cost which are usually cubic curved lines.

Table 3 shows a comparison between the construction cost of superstructure and substructure and total construction cost obtained from this system and the actual design plan (Fig. 2). From these results, construction cost of superstructure by using charts information of manuals, and construction cost of substructure by using the host-computer are sufficiently accurate.

Table 1 Abutment and pier type and economical height

Abutment type	Economical height (m)
Gravity type	$h \leqq 4m$
Inverted T-type	$4m < h \leqq 12m$
Buttressed type	$12m < h$

Pier type	Economical height (m)
Wall type	$h \leqq 8m$
Inverted T-type	$8m < h \leqq 15m$
Column type	$15m < h$

Table 2 Pile diameters used in calculation by host-computer

Pile type	Diameter (mm)
Driven PC Driven RC Driven steel pipe Drilling PC Drilling steel pipe	600,800
Reverse All casing Earth drill Sinso	1000 1200 1500

Table 3 Comparison of construction cost between this system and actual design plan

Calculation method / Details of construction cost	Superstructure (million yen)	Substructure (million yen)	Total construction cost (million yen)
① Actual design plan	597.0	264.0	861.0
② This system	628.5	270.0	898.6
(|① − ②| / ①) × 100	5.3%	2.3%	4.4%

(1 U.S. dollar :approx. 130 yen)

2.3 Total Assessment of type Selection Design Work Time

The total construction cost of the bridge can be obtained by summing up the costs of superstructure and substructure. The case with a lowest total construction cost is evaluated as "first rank economy". All cases are ranked according to total construction cost.

The system also displays the following message on erection workability, maintenance and running comfort.

① Erection workability: "good", "medium" and "bad"
This is evaluated according to the type of superstructure and substructure geological condition, area available for construction and the circumstances (urban or suburb).

② Maintenance: "repainting needed" for steel bridges and "pay attention to anticorrosion" for PC bridges.
In recent years, PC bridges are also affected by salt damage in Japan. So, this is evaluated according to whether construction place is near the sea.

③ Running comfort: "excellent", "medium" and "poor"
This is evaluated based on psychological effects and vibration that driver feels according to the number of joints, construction place and the stiffness of bridge type.

The most suitable selection (Fig. 2) based on total assessment is identical with the actual design plan. And design work time can be reduced to about half.

3. CONCLUSION

(1) The system has made it possible to obtain results that are almost equivalent to that of expert designers due to the integrated knowledge of the expert system, the Specification for Highway Bridges and the River-Crossing Structure Law.

(2) The overall result based on economy, erection workability and running comfort are sufficiently reliable. Consequently, the use of this system can greatly reduce the working time and labor required for the comparative design.

(3) Since a routine is added that allows a designer to select his desired span arrangements and bridge type combination, the system does not make automatic type selections, but can reflect the designer's ideas about type selection. As a result, the system is more practical.

(4) By using fuzzy sets which expresses the ambiguity of design data, the pile type can be selected by the process based on theoretical grounds. The result obtained through this process is sufficiently practical.

(5) By online connection between the host-computer and the workstation, the reliability of pile type selection and the accuracy of substructure construction cost evaluation can be improved.

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