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Safety evaluation system for hydraulic metal structures based on knowledge engineering

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Abstract: A comprehensive safety evaluation system taking the most influential factors into account has been developed to evaluate the reliability of hydraulic metal structures. Applying the techniques of AI and DB, the idea of a one-machine and three-base system is proposed. The framework of the three-base system has been designed and the structural framework constructed in turn. A practical example is given to illustrate the process of using this system and it can be used for comparison and analysis purposes. The key technology of the system is its ability to reorganize and improve the expert system's knowledge base by establishing the expert system. This system utilizes the computer technology inference process, making safety evaluation conclusions more reasonable and applicable to the actual situation. The system is not only advanced, but also feasible, reliable, artificially intelligent, and has the capacity to constantly grow.

Key words: *water conservancy and hydropower engineering*; *safety evaluation*; *one-machine and three-base system*; *knowledge engineering*; *hydraulic metal structure*

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1 Introduction

It is necessary to ensure the safe operation of metal structures in water conservancy and hydropower engineering works. Research on safety evaluation systems for hydraulic metal structures is therefore a top priority.

Safety evaluation is carried out automatically using high-tech computer technology. The use of automated computer technology for this task is infrequent in developed areas overseas, and only a few independent groups have begun to use it domestically. No one, however, has conducted thorough and comprehensive systematic research and design using such methods (Wang and Li 2003; Liu et al. 1997; Zhang et al. 1998; Zou and Hao 2003).

Safety evaluation of hydraulic metal structures targets two critical areas of engineering projects: quantitative and qualitative analysis judgements. The system is able to take the successful experience from the expert system (Wu and Gu 1997; Wang and Ye 2004) and use it to process qualitative judgements with regard to new objects under evaluation. It also utilizes its own software in order to make quantitative judgements about designated evaluation objects. The key technology of this system, however, is its ability to reorganize and improve the expert system's knowledge base by establishing the expert system. This also makes the system extremely reliable.

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2 Construction of system of evaluation targets

In determining the factors (targets) that could compromise the safety and reliability of hydraulic metal structures, it is necessary to look at the standard methods for determining such targets in evaluation projects. The safety evaluation targets that were chosen, according to analysis and research, were the weight coefficients of level I and level II targets and subtargets.

Safety evaluation (one-target system) has object reliability as its overall goal. This in turn is composed of two subtargets: security (weight coefficient $R_1 = 0.7$) and durability (weight coefficient $R_2 = 0.3$). These are then further divided into two additional levels of targets. Currently, the safety evaluation target system contains 29 level II targets in addition to the evaluation targets (the weight coefficients and the standard rank) (Yang 2005).

The synthesis evaluation matrix is $\boldsymbol{Q} = \boldsymbol{RSTJ}^{\mathrm{T}}$, $\boldsymbol{Q} = (q_1, q_2, \cdots, q_{\mathrm{m}})$, where $\boldsymbol{R}$ is a weight coefficient matrix of subtargets, $\boldsymbol{R} = (R_1, R_2, R_3, R_4)$; $\boldsymbol{S}$ is a weight coefficient matrix of level I targets, $\boldsymbol{S} = (\boldsymbol{S}_1, \boldsymbol{S}_2, \cdots, \boldsymbol{S}_{\mathrm{m}})$; $\boldsymbol{T}$ is a weight coefficient matrix of level II targets, $\boldsymbol{T} = (\boldsymbol{T}_1, \boldsymbol{T}_2, \cdots, \boldsymbol{T}_{\mathrm{m}})$; $\boldsymbol{J}$ is a coefficient matrix, $\boldsymbol{J} = (A, B, C, D)$, for large engineering projects, $A = 3.7$, $B = 3.2$, $C = 2.7$, and $D = 2.2$.

The evaluation value of level I subtargets is $q_1 = R_1 \boldsymbol{S}_1 \boldsymbol{T}_1 \boldsymbol{J}^{\mathrm{T}}$;

The evaluation value of level II subtargets is $q_2 = R_2 \boldsymbol{S}_2 \boldsymbol{T}_2 \boldsymbol{J}^{\mathrm{T}}$;

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The evaluation value of level M subtargets is $q_{\mathrm{m}} = R_{\mathrm{m}} \boldsymbol{S}_{\mathrm{m}} \boldsymbol{T}_{\mathrm{m}} \boldsymbol{J}^{\mathrm{T}}$;

The evaluation value of the overall goal is $P = \sum_{i=1}^{m} q_i = q_1 + q_2 + \cdots + q_m$.

The safety rank is determined according to the GB50199-1994 standard. For large engineering projects, the safety rank is divided into three levels: when the value of evaluation P meets the condition $P \geqslant 3.2$, the safety rank is level I (safe); when $P \geqslant 2.7$, the safety rank is level II (intermediately safe); and when $P < 2.7$, the safety rank is level III (unsafe).

3 Framework design of evaluation system

The evaluation system foundation integrates the characteristics of domestic and foreign expert systems and unifies the actual situation of the domain. The design idea of a one-machine and three-base system is proposed. It is a combination of an intelligent inference machine, a knowledge base (KB) system, a database (DB) system, and a method base (MB) system. The domain contains interrelated safety rules, regulations, and norms. The inference process draws upon the knowledge and evaluation experience of experts to reorganize its knowledge base. The knowledge base, database, method base, and synthesis inference machine together make up the integrity evaluation system. Using artificial intelligence and database technology, one can, with the methods used in the expert and database systems, make judgements of the rank standard of qualitative projects and analyze quantitative projects (Wu and Gu 1997; Wang and Ye 2004; Yang and Zheng 1990; Hayes-Roth 1984; Giarratano and

Riley 1998; Barr and Feigenbaum 1981; Waterman 1985; Hayes-Roth et al. 1983; Lin et al. 1988; Wang 2000).

The framework of the overall evaluation system has a four-level structure (Figure 1):

(1) The first level is the system control. This aids in the transfer of system modules and provides man-to-machine contact on the surface level of system operations.

(2) The second level contains both the synthesis intelligent inference machine and the evaluation subsystem. The synthesis inference machine, through the management system and the transfer of the three bases, is what carries out the inference. The evaluation subsystem is used to construct the safety evaluation system, the evaluation model, the synthesis analysis evaluation module, and so on. This subsystem is what calculates the evaluation rank.

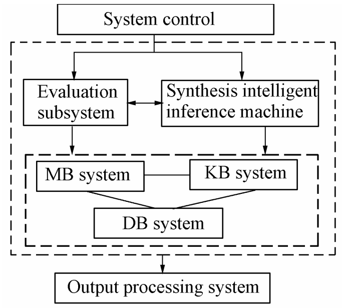

Figure 1 Framework of evaluation system

(3) The third level of the evaluation system is the management base system, which is composed of a three-base system. This includes the KB system, DB system and MB system. This level is used primarily for system memory in terms of the management of knowledge, data, and methods via the management base system (which executes management operations for the entire three-base system). This enables the user to complete tasks such as input of various technical parameters (e.g., gate and hoist machinery), inquiry about existing knowledge (e.g., former examination records), and validation of rank standards. It also aids the user in regard to output methods (e.g., producing a report with results).

(4) The fourth level is the output processing system, which is a substructure of the system used to demonstrate, print, draw, and preserve the system's analysis, computations, and judgements (such as any related data, writing materials, graphs, figures, or other forms).

Through interaction with the evaluation subsystem, the user may effectively and efficiently complete the evaluation process. The system transfers the management subsystem data (of the knowledge base) to the inference subsystem, where a complete judgement of the rank standard of the qualitative project will take place. (It transfers data to the management subsystem of the database and the method base to complete this judgement). After the rank standards of all project targets are determined, the system uses the synthesis evaluation model (through computation of an evaluation matrix) to obtain a result, which in turn allows the user to arrive at a concrete conclusion. These results (e.g., the test data and the rank standards of targets) are preserved in the system's database.

4 Design of three bases of the system

4.1 Design of KB system

The main function of the KB system is to store complex information of types and sizes that cannot be deposited or saved using the common database and model base systems (e.g., regulations and standards, or expert experiences). These, in turn, constitute the criteria for the system's judgements. The knowledge management system's framework is described in Figure 2 below.

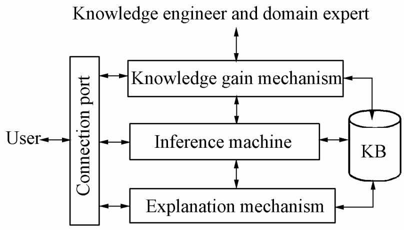

Figure 2 Framework of knowledge management subsystem

The knowledge base refers to the domain knowledge upon which inquiries rely in order to find solutions. It includes factors such as basic factual knowledge, judgement rules, and other related information. There also exist additional knowledge-expression technologies, including rules, semantic networks, frames, scripts, knowledge-expressed languages (e.g., KL-ONE RDF, which was recently used to express web-based knowledge, and OWL, the language of the described main body) (Giarratano and Riley 1998; Russell and Norvig 1995). These technologies have advantages and disadvantages. For instance, the expression potential is quite strong, but this makes the corresponding inference process complex.

Presently, the most popular type of expert system is based on the rule system. The rule system allows acquired knowledge to be easily understood and constantly expanded. It also allows the user to easily establish an explanation machine because the front part of the rule indicates the condition that initially activated this rule. The explanation machine is thus allowed to obtain an inference chain of judgements (by referring back to the rule from which it originated) to arrive at some conclusion (Hayes-Roth 1985).

When evaluating the safety rank of a given goal, an "If…Then…" pattern is commonly thought to be capable of sufficiently expressing the experiential knowledge of experts. This evaluation system has also used the expression of the production pattern based on this rule.

With the exception of judgement rules for rank, the system also has designed rules for restriction and suggestion. To judge the rank standard of targets, judgement rules mainly use these restriction rules, which in turn include rules for the restriction of an identical target as well as the mutual restriction of and relation between different targets. This is mainly used to enhance the degree of accurate evaluation. The rules of suggestion are what provide the corresponding reorganization suggestions in each of these rank situations.

For example, the restriction rules of evaluation are as follows:

CR1: IF the track seriously wears, THEN the main wheel (or slide) seriously wears.

CR2: IF the main wheel (or slide) seriously wears, THEN the track seriously wears.

The knowledge gain mechanism is responsible for establishing, revising, and expanding the knowledge base. It is an important module that converts specialized knowledge into solutions from which experts' questions (or questions from another source of knowledge) can be solved (Rush and Wallace 1997). The knowledge gain mechanism may be operated manually, semi-automatically, or automatically (in regards to the knowledge gain method).

The explanation mechanism displays the decision process and generates a response to the user's inquiry. It allows the user to understand what the program is deciding and why. To see why the system arrives at a specific conclusion, it looks back to the inferences made (which the knowledge base preserves) and translates them into an easy-to-understand expression (using common language).

The management of knowledge is sustained by the management subsystem of the knowledge base. It allows knowledge to be input, revised, transferred, inquired about, and so on. Knowledge can constantly grow and be renewed by the learning system of the machine. In order to ensure the accuracy of the knowledge base, it is necessary to first check the knowledge base for errors. This examination of the knowledge can be divided into static examination and dynamic examination. When the user renews the knowledge base, the system checks for duplicate rules, redundant rules, contradictory rules, and so on, and maintains the uniformity of the knowledge likewise.

The inference machine is the core part of the expert system. It is responsible for implementing (explaining) solutions to questions raised. It helps explain knowledge by showing how the solution was generated (e.g., showing which strategy was used) and then records this result in the knowledge base to further that system's ability to achieve the ultimate objective. The programming of the inference machine is thus not directly related to the content of the knowledge base, so one does not need to revise the inference machine as one might need to manually revise the knowledge base.

The primary function of the inference machine subsystem is two-fold: to simulate the domain expert's thought process (by inferring and reverse inferring) and to execute relevant solutions to questions raised to allow for system control. When the system exerts its inference, it communicates to the management subsystem (through the three-base system) before and after it arrives at a solution. This enables intercommunication between the three bases (e.g., the management subsystem) and the inference machine.

4.2 Design of DB system

In the process of designing the database, it is necessary to first carry out demand analysis: determining the data item(s) of the application domain and performing data manipulation. Once a concept for the database is arrived at, it is necessary to then create a design for the database. The next step is to design a logic database to form specific data patterns. Finally, a physics database is designed and the memory structure of the database is optimized. The demand analysis and conceptual designs may be independent of any system of database management. The designs of the logic and physics databases, however, are in close correlation with the system of database management.

In designing the concept database, the entity and relationship data model (E/R model) is used. The primary goal during the conceptual design stage is confirmation of entities (any physical object or concept), relations among entities, and attributes of entities. In this system, each kind of hydraulic metal structure can be regarded as an entity, whereas size, material, and so forth would be attributes.

Figure 3 shows an example of a conceptual view of an E/R model. Here, gate and faceplate describe two different entities. Gate number, pattern, structure, height, width, design water head, operating condition, and self-weight are all attributes of the gate. The faceplate number, length, width, and design thickness are all attributes of the gate's faceplate. Both the gate and the faceplate are marked with a number.

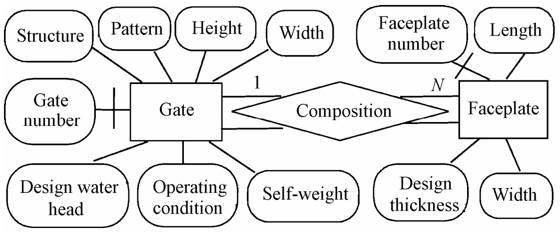

Figure 3 E/R chart of gate and faceplate

The diamond shape in the middle describes the relation between the gate and its faceplate. The double line connecting the two expresses the entire participation, namely that each gate always has a corresponding faceplate. Here, the number 1 and the letter *N* express the ratio of the relation (each gate may be composed of *N* faceplates).

This type of relational database is widespread and fairly popular. An object may be described by one or more of its relations. These relations are composed of various attributes, and the attributes are each of a certain type.

In modern DB systems, in addition to value type (e.g., int, or real), character string type (e.g., char, or varchar), and date type (e.g., date), binary types of text and graphs are supported. For instance, a gate and its primary components may be described by the following relations:

(1) Table for the gate (number, pattern, structure, height, width, design water head, operating condition, and self-weight).

(2) Table for the gate components (gate number, component number, component name, section pattern, section size, length, and material).

This example abbreviates the types of concrete data and relations between the two tables (the gate and the gate components). Listed in parentheses are the entity's attributes, while the unique gate number and corresponding gate component number are described as number, gate number and component number.

According to this relational pattern one can easily write an SQL sentence and thus establish a physics database through DBMS. When inserting data, DBMS can inspect the uniqueness of each main key in each relational table. In the process of data renewal, the inspection of semantic restraint is realized by the memory process through definition of the process of saving and viewing, and the view mainly helps to define the report form.

4.3 Design of MB system

The MB system and its management subsystem computer software are used in the memory and transfer management of method information and in many programs of computational analysis related to engineering safety and evaluation. The entire control system relies heavily upon the MB system and functions according to the analysis of demand and judgement: goal of computation → name of program → input data (from database) → analysis and computation → output achievement (to database).

The MB system includes the following: the module of pre-treatment and the testing of examination data, the module of statistical analysis of examination data, the program of computational analysis of structure, the program of computational analysis of hoist power, the module of synthesis analysis and evaluation, and the module of decision-making assistance (and so on) used in quantitative analysis and judgements of the condition of hydraulic metal structures.

The system was programmed using Visual Basic and used a design that combined a drop-down menu with multiple windows. The main screen is composed of modules of the system operation, evaluation subsystem, management of data input, MIS, synthesis evaluation analysis, system management of safety and parameters, management of the system environment and equipment, and management of online help. One can use these control modules to input parameters in order to generate an evaluation.

5 Analysis via example of evaluation system

It is assumed that there is a large-scale sluice that has operated safely for 30 years. The steel gate has a fixed pulley and welded structure. The size of the gate is 6 m×4 m (the design hydraulic head is 4 m), but there are some design flaws in the gate due to poor management. After carrying out a safety examination and safety evaluation of the metal sluice structure, the evaluation conclusion is that the gate's structure is in danger. In light of the question, the reinforcement and renewal processing should be conducted. For example, the supporting wheel should be repaired, the marginal beam of the gate and water seal should be replaced, any design flaws should be reviewed and fixed, improved management software should be created, and so on.

With the data and examination materials, one can use this system to compute and evaluate safety. The process is described below.

5.1 Determination of targets and model of evaluation

The evaluation subsystem evaluates the system's safety. Presently, this system contains only the model of synthesis evaluation.

First, the level I and level II evaluation targets are selected. Then, the parameters are input according to the prompts and the weight coefficients for all targets are determined. (The 21 evaluation targets are determined by the user: $t_1, t_2, \cdots, t_{21}$). After the choice or input of the parameters according to the prompts has been completed, the system demonstrates the model established and determined by the user. If the user needs to revise something, the system will return to the previous step and the user can revise it until satisfied.

5.2 Input and examination of test data and material

After inputting the relevant data, the system examines its logical accuracy. When there is an error in the data, the system will display an error message that details the problem or the logical inconsistency encountered.

5.3 Judgement of target rank and computation of evaluation value

The evaluation subsystem judges the rank standard of target items t_1 through t_{21}.

If t_i is obtained by computation, the evaluation subsystem uses the method base management module to obtain the computation's parameters. This in turn activates the corresponding computation module, which calculates the rank standard of t_i.

If t_i is obtained by inference, the evaluation subsystem uses the knowledge base management module, and it refers to the inference machine to judge the corresponding rank standard. In the inference process, if the data does not satisfy the corresponding restraint rule, the user can revise the original fact.

The judgement process of the rank of qualitative targets is as follows (Figure 4):

(1) Using the restriction rules of evaluation, the inference mechanism checks the fact input by the user for logical accuracy.

(2) Using the target item, the system judges the rank standard according to corresponding rules of rank judgement.

(3) The system again checks the rank standard to verify that it satisfies the restriction rules of evaluation.

(4) The final evaluation is produced.

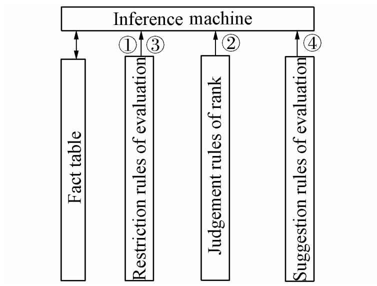

Figure 4 Inference process of evaluation index

After the rank standards of all targets are determined, the evaluation subsystem uses the evaluation matrix to calculate evaluation values of all subtargets and the overall target.

The resulting evaluation is as follows:

Level I subtargets: $q_1 = 2.17$;

Level II subtargets: $q_2 = 0.67$; and

Overall target: $P = 2.84 > 2.7$.

5.4 Synthesis evaluation analysis

According to the evaluation value of the overall target, the system utilizes the knowledge base management module to determine the safety rank of the evaluation object and ultimately produces a corresponding suggestion (using the suggestion rule of evaluation). The system then demonstrates the final result of synthesis evaluation and policy-making analysis.

The conclusion of the evaluation is as follows: the equipment of the hydraulic metal structure is evaluated as level II equipment (intermediately safe) and it is suggested that renewal and reinforcement processing be carried out.

Suggestions of the evaluation are as follows:

(1) The marginal beam of the gate and water seal should be replaced and the main wheel should be repaired.

(2) The structures responsible for movement should be strengthened.

(3) Once reinforced and repaired, movement-system management should be considered in order to create suitable and safe conditions for movement.

By utilizing the realization and contrast analysis in the example above, the system's feasibility and accuracy are thus demonstrated.

This system utilizes the computer technology in the inference process of knowledge, offering satisfactory solutions to many questions. For example, the personnel who examine and evaluate the system generally have a difficult time judging a project's rank with regard to the targets of manufacturing, installation, and performance, due to various reasons that diminish the quality certificate or acceptance certificate. But in using the experiential knowledge of experts through this system, a more efficient and easy-to-understand solution is reached (via the inference judgement using inference technology). This allows safety evaluation conclusions to be more reasonable and applicable to the actual situation.

6 Conclusions

(1) The hydraulic metal structures safety evaluation system consists of integrated hi-tech systems that use the most modern computer technology, such as software engineering, for safety monitoring and evaluation of hydraulic metal structures. This system is not only advanced, but also feasible, reliable, and user-friendly, and it has the capacity to constantly grow. It is a single but immensely powerful platform used for the fast and effective evaluation of hydraulic metal structures.

(2) The creation and use of the safety evaluation intelligence system of hydraulic metal structures is an inevitable trend for future development of safety monitoring of hydraulic projects. Along with the constantly expanding technology for safety monitoring and evaluation, the safety evaluation system of hydraulic metal structures also has a wide range of applications and will be playing an increasingly vital role in the field of hydraulic safety.

(3) This paper only describes preliminary study and design of the system. The functions of each of the system's components still have much room for expansion. For example, the evaluation model, using technical knowledge such as data excavation, can be expanded in design to include new knowledge based on new discoveries. This constantly increases the level of efficiency and function of the system's computations for its various rules.

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