COBDA - 콘크리트 교량의 노후화를 평가하는 전문가 시스템

COBDA - An Expert System for Concrete Bridge Deterioration Assessment

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Abstract

Existing assessment methodologies present a considerable problem because of fuzzy situation of deterioration mechanism of concrete bridges; namely, qualitative, subjective or inconsistent. This paper discusses current assessment methods in aspect of uncertainty. The expert system, COBDA, is developed for consistent and fast assessment of deterioration of concrete bridges. Briefly introduced in this paper are the structure of expert system and several methodologies for decision making of deterioration situation and providing repair option. COBDA is configured by PROLOG for personal computer, which is made up of 3 different methodologies: Performance Index, Fuzzy logic approach and expert system shell based on Bayesian subjective probability. The methodologies are illustrated and discussed by comparison of condition assessment results in a case study.

1. INTRODUCTION

Concrete Bridge Deterioration Assessment-COBDA, is a comprehensive expert system for diagnosis and prognosis of deterioration of concrete bridges. For the development of COBDA, use is made of PDC PROLOG (1) as a main expert system development tool. Three different methods are suggested as alternative solutions of uncertainty problems which occur in data processing: Performance Index (2), Fuzzy

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Logic (3) and Bayesian Subjective Probability Theory (4). Knowledge acquisition is a crucial and difficult procedure for building the expert system, therefore the paper discusses knowledge sources and the assemblage of the knowledge base in COBDA. The COBDA inference engine is configured by PDC PROLOG, FORTRAN (5) and Bayesian expert system shell (6). This inference procedure is supported by user friendly interface tools, i.e. menu driven user interface tool, reference window, editing tools and user help tool. These are also discussed in the paper. The paper explains the COBDA software as a program package and 11 analysis and consultation modules.

2. CONDITION ASSESSMENT OF CONCRETE BRIDGES

2.1 Condition assessment

Condition assessment of concrete bridges is apparently far more difficult than the analysis of bridge design. Though the structure physically exist and the data for testing and measurement of the concrete bridge are available, the assessment involves uncertainties due to the difference between reality and design concept, heterogeneous concrete material and complexity of deterioration mechanisms. Even if a proper sampling and testing procedure to obtain specific data for the assessment is chosen, the information will not be precise in itself and some uncertainties will remain since the tests cannot be totally representative and the results will always be subject to some testing error, especially in the case of non-destructive examination methods. (7) With regard to the interpretation of test results, there are also a number of uncertainties arising from the potential effects of a combination of deteriorating mechanisms.

2.2 Defect assessment

Structural defects of concrete bridges are shown in the form of various defect on the concrete surface. In evaluating existing condition of concrete bridges, it is important to define and describe the defect objectively and consistently. To achieve this objective, the defects are evaluated in terms of defect type, extent and severity. The following defects can be chosen as a main visual deterioration symptom in the concrete bridge.(8)

- □ crack : corrosion-induced crack, structural crack, ASR crack, freeze-thaw crack, intrinsic crack(plastic shrinkage crack, plastic settlement crack, settlement crack, long-term drying shrinkage crack, crazing, early thermal contraction)
- □ deterioration : scaling, popout, spall, delamination, joint leakage, rust stain, efflorescence/exudation, Surface distress (discoloration, incrustation, honey-comb, air void, water void, stratification, joint, cold joint, cold joint line, sand pocket,

sand streak, stalagmite, stalactite)

For a specific defect type, both severity and extent are determined in the form of a linguistic scale. In the case of severity, a level of deterioration can be expressed by using the adjective "severe", "moderate" and "mild". While for assessment of the extent of a defect, the adjective "abundant", "medium" and "low" is used.

In-depth testing parameters can be divided into six causes of deterioration of concrete as shown in Table 1. The level of deterioration can be determined by combining these parameters.

Table 1 In-depth testing parameters

Cause	In-depth testing parameters
Corrosion	cover depth, half-cell potential, resistivity resistance, linear polarisation, chloride content, section loss, extent of corrosion, crack width, rust stain degree, spall size
ASR	crack width, popout size, exudation degree, expansive strain, extent of ASR
Sulphate attack	crack width, spall size, Figg permeability, expansion rate, extent of sulphate attack
Acid attack	efflorescence degree, Schmidt hammer, Pundit, expansion rate, extent of acid attack
Freeze-thaw	crack width, scaling depth, spall size, extent of frost
Surface erosion	scaling depth, Schmidt hammer, abrasion depth, extent of surface erosion

2.3 Characteristics of bridge inspection data

Condition assessment of concrete bridges may be composed of information collecting and decision making processes. Data collection may contain errors concerning test sampling, testing, or data management. These uncertainties can be diminished by using conventional probability theory and statistics. The participation of a human expert involves other uncertainties in the information, the algorithms for processing the information and the structure of the information system. Conventional probability theory can not deal with these fuzzy features.

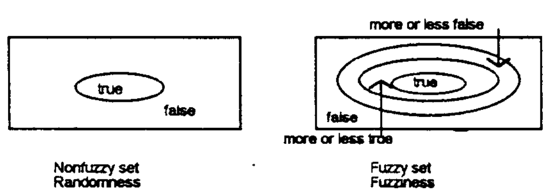

Fig.1 Randomness Vs Fuzziness

Information available for condition assessment of concrete bridges can be divided into objective and subjective parts. The objective part is measurable, countable or quantitative information which is produced during testing whilst the subjective part includes qualitative information such as the significance of a crack on the safety of concrete bridges. Most of the decision making processes, in reality, lack proper information which is precisely known. This imprecision can be attributed to both fuzziness and randomness in the parameters. Zadeh (3) cited that in most decision making processes the nature of the source of imprecision is fuzziness rather than randomness. Randomness has to do with uncertainty concerning membership or non membership of an object in a non fuzzy set. Fuzziness , on the other hand, has to do with classes in which there may be grades of membership intermediate between full membership and non membership. (see Figure 1)

3. VARIOUS METHODOLOGIES FOR ANALYSIS IN COBDA

COBDA suggests 3 different methods to solve uncertainty problems concerning the complexity of concrete bridge evaluation, for example, vague deterioration mechanisms, ill organized inspection procedure etc. These methods are Performance Index, fuzzy logic and Bayesian subjective probability. Although these produce different results, they are very useful data since the obtained data allow to refine and calibrate each method.

Uncertainty problems occur when the problems cannot be defined with satisfactory precision, i.e., the characteristics of the phenomena in the domain to be considered are complex, the values come from scarce data and so on. In the traditional approach, the uncertainty can be treated by using random variables and stochastic processes. This approach might be partly successful. Also it is generally accepted that some features of analytical or mathematical models are, to various degrees, associated with subjective engineering decision. This makes an engineer's interest turn to modelling by using expert judgement, human thinking and approximate reasoning. In dealing with uncertainty problems, use can be made of possibility theory, subjective probability, fuzzy logic and evidence theory. COBDA attempts to solve uncertainty problems in the bridge condition assessment domain by using fuzzy logic and subjective probability theory.

The Performance Index (PI) method was developed for fast and cursory evaluation of the physical condition of concrete bridges. This method originally proposed by Cabrera (2), introduces the concept of quantitative evaluation of concrete performance, in order to implement rapid ranking of the overall state of concrete bridges using the result of the observation of signs of defect and weighting scales based on severity and extent. This procedure includes visual inspection of concrete surface or near surface damages which can be described in terms of severity and extent and takes exposure condition into account as modifier. The weighting scale is divided into 3 categories: mild, moderate, severe. The PI considers main defects in a concrete and reflects the overall condition of concrete.

The principle of computing the PI is based on the deduction method, where all the defect weights or deterioration cause weights are summed and subtracted from a value of 100. The PI value ranges from 0 to 100, where 100 is assigned to a concrete with no visible defect or no deterioration cause.

In a bridge assessment procedure, it is crucial to integrate all defects in an element and to combine subjective rating of each element with accuracy and consistency. Fuzzy set theory has been used (10) in order to handle these problems, specially the combined effect of various defects on a concrete bridge which are difficult to assess objectively and consistently. This defect combination method enables to model the interaction of various defects considering the characteristics of each defect i.e. the membership function. Using fuzzy logic, the extent and severity of each defect or each cause expressed in terms of linguistic variables can be combined. After deciding the condition rating of each element, the overall condition rating of the whole bridge is implemented by using Fuzzy weighted averages (11) and structural importance factors (12).

The PEXPERTX expert system shell belong to the family of Bayesian expert system shells with features resembling some of those of the PROSPECTOR system(13). The PEXPERTX enables reasoning to measure the degree of certainty in each knowledge base, using a subjective Bayesian updating procedure. As input data are gathered by using logical AND, OR, NOT etc., with certainty factors expressed in terms of odds in each rule based knowledge base, some hypotheses(conclusion) may be definitely established, whereas others may become only more or less likely or even excluded entirely.(9)

4. DEVELOPMENT OF COBDA

The development of COBDA includes the following phases.

The first phase was devoted to a general literature review of the subject in order to obtain some information of deterioration and assessment of concrete bridges, application of expert systems and mathematical tools i.e. fuzzy logic and Bayesian probability theory. The second phase narrowed the subject down to a specific concrete bridge assessment. It also included the acquisition of the necessary knowledge base and development of the inference engine. The third phase incorporated the knowledge base and inference engine, upgraded the artificial intelligence of the knowledge base and converted them in user-friendly software. The final stage was to test and refine

COBDA by comparing the results of COBDA with actual concrete bridge special investigation reports and consultation with concrete bridge experts.

The COBDA knowledge has been obtained from textbooks, specifications, research papers and experience of concrete bridge engineers.

The COBDA knowledge can be categorised by the following sub-domains.

· Deterioration of concrete bridges, inspection of concrete bridges, Maintenance and repair of concrete bridges, Assessment of concrete bridges, Uncertainty problems of inspection data

The COBDA inference procedure is divided into 2 parts: the main implementation part including input data system, computing tools of the PI, Fuzzy logic & the chloride diffusion model as an analysis system and user interface part as supporting tools. These inference engines are characterised by element analysis, internal database converter, menu driven and reference window system. COBDA is configured for 4 high density 3.25 inch floppy disks for IBM or compatible microcomputer for personal use. Two disks contains inference engines that are stand alone execution files while the other two disks include system files for reference windows & contexts and data files for knowledge and data bases. In COBDA, when the program was under development, some system features, i.e. weighting scale of visual defect or cause have been calibrated by comparison of results from 3 different methods. Specialists and engineers from Local Government and consultants tested COBDA using a number of reports of actual older bridges with which they were familiar.

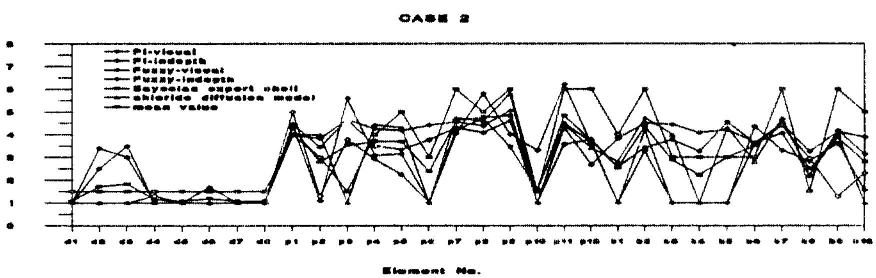

Fig.2 Comparison of results from various methodologies

An example of the output of the evaluation of a concrete bridge is given in Figure 2. The value of Performance Index (0-100), verbal description of condition assessment (no corrosion, unacceptable damage and so on) and weight loss (%) based on the chloride diffusion model are converted into fuzzy logic rating values 1 to 8. The value 1 indicates very good condition whilst the value 8 means dangerous.

5. Conclusion

There were many difficulties in configuring COBDA. PROLOG programming is not easy task because of self owned execution parts, i.e. recursion and repetition in PROLOG. During implementation, PROLOG consumes a lot of memory. This memory problem cannot be solved satisfactorily. The available memory in COBDA is limited to approximately 40 elements and 150 grid locations. Inference procedures of COBDA are proved to be sound in the aspects of program accuracy and utility of program. Even with inexact information of the condition assessment domain, COBDA can make quite a reasonable decision. The condition assessment by COBDA is not only more detailed, consistent and objective but also economical and less time consuming.

Even though COBDA has consistency and completeness, COBDA can be said to be unfinished. COBDA requires continuous upgradation and updating of knowledge.

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