Development of an Expert System for Maintenance and Repair of Masonry Barrages

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Abstract. The construction of large hydraulic structures such as barrages is very expensive. Regular maintenance is important to monitor the structures in order to prevent any unexpected faults or structural failure. Since only few human experts are available in this field, it is important to collect their experiences and make them available for use by other engineers. This paper presents the development and application of an expert system for diagnosis of the different types and classes of problems that may occur in different elements of masonry barrages. The developed expert system helps to diagnose the possible causes and suggest an appropriate method of repair. The proposed expert system is developed using CLIPS 6.0 and the user interface is designed using Visual Basic 6.0. These programs are included under one executable stand-alone package. The developed expert system was designed and tested on several real cases.
Keywords: Expert Systems, decision tool, maintenance, repair, masonry barrages.

1 Introduction

Maintenance of major civil engineering structures is very important because the loss of performance of these structures can lead to functional deteriorations that may result in accelerated ageing, additional operational and maintenance costs or catastrophic failure. Maintenance is very complex decision-making process, and requires experts to provide accurate decisions. Maintenance requires detailed study of the structure and collection of accurate data from visual observations, monitoring measurements, calculated data and documents related to design, construction processes, construction materials and repair works which may have been performed on the structure. Inspection of changes that take place e.g., in applied load or in circumstances surrounding the structure, or corrosion and failure of some parts of the structure is very important. Maintenance of hydraulic structures is a very complicated process due to the large number of factors that affect the structure, the foundation soil, water flowing around the structure, seepage under or through the structure, and applied live load on some elements of the structure.
Expert systems (ES) is a branch of artificial intelligence (AI) that has achieved considerable success in recent years. The area of expert systems involves investigation into methods and techniques for constructing human-machine systems with specialized problem solving expertise. Expert system has many applications in the field of water engineering such as construction, design, planning, operation and maintenance of hydraulic structures.

A significant amount of research has been carried out to manage the performance and safety of hydraulic structures using expert systems. For example expert systems have been used for the assessment of damage to bridges and repair of different types of bridges (e.g., Chiang et al. (2000); De Brito et al. (1997); Furuta and Hirokane (1998); Kushida et al. (1997); Miyamoto et al. (2001) and Zhao and Chen (2001)), and safety and performance assessment of dams (e.g., Andersen et al. (1999); Andersen et al. (2001); Andersen and Torrey (1995); Peyras et al. (2006) and Serre et al. (2006)). This study presents the development of an expert system for maintenance and repair of masonry barrages. The developed expert system aims to identify the problems and their causes and to suggest the appropriate method of repair to protect the structures. The expert system was built using **CLIPS 6.0**. A user interface was designed using **Visual Basic 6.0.** The developed expert system is easy to use for entering the data and getting the results through a number of screens. The proposed program was validated against many real cases.

2 Maintenance and Inspection of Masonry Barrages

Barrages are vital structures with high construction cost, so regular maintenance for these structures is very important to ensure their safety and ability to provide the required service. The structural performance of barrages may be affected by many circumstances such as the actual loads exceeding the original design loads, man-made changes, environmental changes and deterioration of the structure. This study relies on the use of all available data from visual inspection, monitoring, outputs of numerical models, as well as design and construction data to evaluate the current and the future state of the structure. Inspection of the structure allows the maintenance engineer to be kept aware of the condition of the assets entrusted to his care (Bray and Tatham (1992)). The purpose of inspection is to provide a check on the condition of a structure and its associated features as continuously as possible. Inspection is an essential part of the safety evaluation of the structure. It must be guided and determined by continual awareness, recognition, and understanding of the primary causes of a structure failure. An effective inspection program is therefore important to maintain a structure in a safe condition. Inspection can be categorized according to the intervals between inspections into; annual inspection, semi-annual inspection, routine inspection, special inspection, and emergency inspections. The type of inspection conducted will depend upon the purpose of the inspections. In general, the shorter the interval between inspections, the greater is the chance of observing the development of adverse conditions.

3 Expert Systems

Artificial intelligence is the science of making machines do things that would require intelligence if done by men (Kumara and Soyster (1986)). Expert system is a branch of artificial intelligence that makes extensive use of specialized knowledge to solve problems at the level of a human expert. It is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Expert system depends on the knowledge acquired from human experts. The basic concepts of a knowledge-based expert system are illustrated in Figure (1). The user supplies facts or other information to the expert system and receives expertise in response. Internally, the expert system consists of two main components.

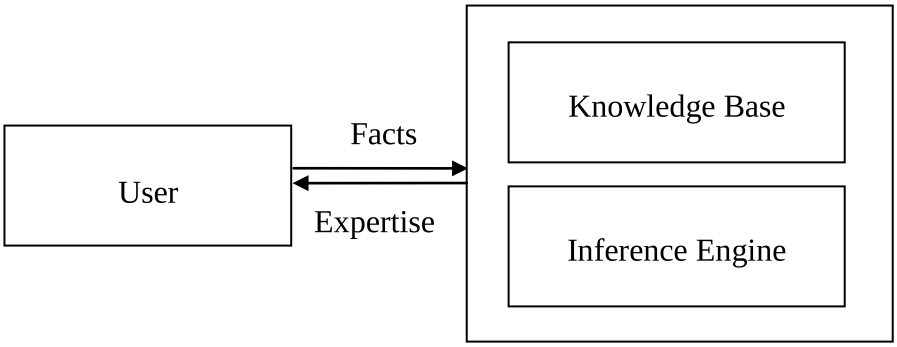

Fig. 1. Basic Concepts of Expert System

The knowledge base contains the knowledge with which the inference engine draws conclusions. These conclusions are the expert system's responses to the user's queries for expertise (Giarratano and Riley (1962)).The knowledge of an expert system may be represented in many ways. It can be encapsulated in rules and objects. One common method of representing knowledge is in the form of IF... THEN type rules. Expert systems have experienced tremendous growth and popularity since their commercial introduction in the early 1980s. Expert systems have been applied to many fields of knowledge such as: chemistry, electronics, medicine, engineering, and geology. The use of expert system has many advantages including increased availability of expertise at reduced cost, reduced risk, improved permanence, the use of multiple expertise, increased reliability, fast response, availability of intelligent tutor, intelligent database and steady, unemotional, and complete response at all times. However, lack of knowledge and expertise is considered the main limitation of building expert systems (Giarratano and Riley (1962)).

4 Knowledge Acquisition and Knowledge Representation

Knowledge acquisition is considered the bottleneck of the expert system building process. One of the major difficulties at this stage is to identify and capture knowledge relevant to the intended application. Knowledge acquisition is probably the most important task in the development of an expert system (Anna (1986)). The required knowledge for the expert system for maintenance of major hydraulic structures (ESMHS) has been acquired through three main steps. The first step involved reviewing the literature in the related fields, studying and analyzing previous experiences in the field of maintenance of masonry barrages, and gathering the available knowledge from textbooks and research publications. The second step was achieved by acquiring knowledge through case studies to obtain and evaluate the existing experiences in this field, through interviewing experts. This work was finalized using a questionnaire. The questionnaire was the final and the main step to collect experts knowledge. The objectives of the questionnaire were to bring local expertise of the experts in the field of maintenance of masonry barrages in order to help identify the causes of problems and suggest a suitable method of repair for each problem. Table (1) shows a typical questionnaire that was used for collecting data from experts. The experts were asked to give a possibility to the causes of different problems and propose a suitable method of repair for each case.

Table 1. A typical questionnaire used to collect experts knowledeg

The type of structure: Masonry Barrage					
The elements: Arch					
The material of construction: Masonry					
Problem	Possible Causes	L	M	H	Proposed Method of Repair
Decay of material	- Weathering - Thermal changes - Shrinkage				
Decay of mortar	- Weathering - Thermal changes - Shrinkage				
Arch ring deformation	- Over load - Under design - Accident hit from passing traffic				

All the collected data for masonry barrages were classified, analyzed and then coded. Tables (2 to 7) show samples of the items and the corresponding codes. Table (2) shows the codes used for barrage type. Tables 3, 4, 5, 6 and 7 show sample of codes used for barrage elements, barrage materials, problems, causes of problems, and methods of repair respectively.

Table 2. The codes used for barrage type

Code	Item
B01	Masonry Barrage
B02	Plane Concrete (PC) Barrage
B03	Reinforced Concrete (RC) Barrage
B04	Mixed type Barrage

Table 3. A sample of codes used for barrage elements

Code	Item
E01	Arch
E02	RC bridge
E03	Steel bridge
E04	Hand rail

Table 4. A sample of codes used for barrage elements materials

Code	Item
M01	Stone
M02	PC
M03	RC
M04	Steel

Table 5. A sample of codes used for type of problems

Code	Item
P01	Decay of material of arch
P02	Decay of mortar of arch
P03	Arch ring deformation
P04	Cracks in the arch

Table 6. A sample of codes for causes of problems

Code	Item
C01	Weathering
C02	Thermal changes
C03	Shrinkage
C04	Over load

Table 7. A sample of codes for repair actions

Code	Item
R01	Replace decayed parts
R02	Re-point
R03	Reduce loads

5 Knowledge Representation Tool

In this study the CLIPS software was used for representing the knowledge. CLIPS (C Language Integrated Production System) CLIPS has beens designed to facilitate the development of software to model human knowledge or expertise (Giarratano and Riley (1962)). In CLIPS the main structure of the expert program is FACTS and RULES. Facts are one of the basic high-level forms of representing information in a CLIPS system. Each fact represents a piece of information. Rule is similar to an **IF** … **THEN** statement in a procedural language. An **IF** … **THEN** rule can be expressed in a mixture of natural language and computer language as follows: **IF** certain conditions are true **THEN** execute the following actions. The rules are coded. This code is transformed into CLIPS.

In this study, each problem has been solved by two rules. The inputs of the first rule are; Barrage type (B), Element (E), Material of construction (M) and Problems (P). The outputs are the causes (C) of the problem which is used as input to the second rule to get the method of repair (R) as output of the second rule. All rules were built using the coded data for each element and put in tables. A sample of coded rules is given below:

Rule one:

If B = B01 (Barrage type)
E = E01 (Element)
M = M01 (Material)
P = P01 (Problem)
Then C = C01 or C02 or C03 or C72 (Causes)

Rule two:

If C = C01 (Cause)
Then R= R60 (Repair)

The bases of the rules adopted were experts opinion. 25 experts participated in the program including 12 expert academic staff, 10 experts from Ministry of Water Resource and Irrigation, and 3 experts from hydraulic research institute, Egypt. The total number of rules for masonry barrage problems is 135. A sample of the coded rules is presented in Table (8).

Table 8. A sample of coded rules

L.H.S				R.H.S	
B	E	M	P	C	R
B01	E01	M01	P01	C01	R60
				C02	
				C03	
				C72	
B01	E01	M01	P02	C01	R02
				C02	
				C03	
				C72	
B01	E01	M01	P03	C06	R03
				C07	R14
				C73	R43
B01	E01	M01	P04	C02	R03
				C07	R44
				C73	R45

6 The Proposed Expert System for Maintenance and Repair of Masonry Barrages

The proposed expert system for maintenance of hydraulic structures (ESMHS) was developed using **CLIPS 6.0**, and the user interface was designed using **Visual Basic 6.0.** The program consists of facts (data base features) and rules (logic based features). It is capable of estimating causes and methods of repair of different problems. This program is included under one executable stand-alone package. So, the package is easy to use by interested users as shown in the next print screens. Figures (2 to 8) show how the user can define a problem and get the results from the program.

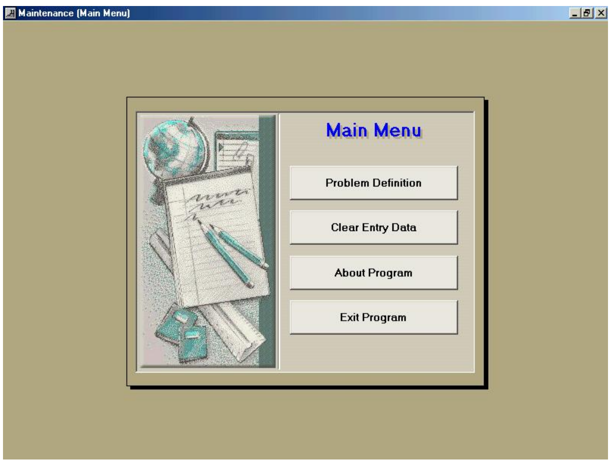

Fig. 2. Main menu (helps the user to define the problem and provides help on the program)

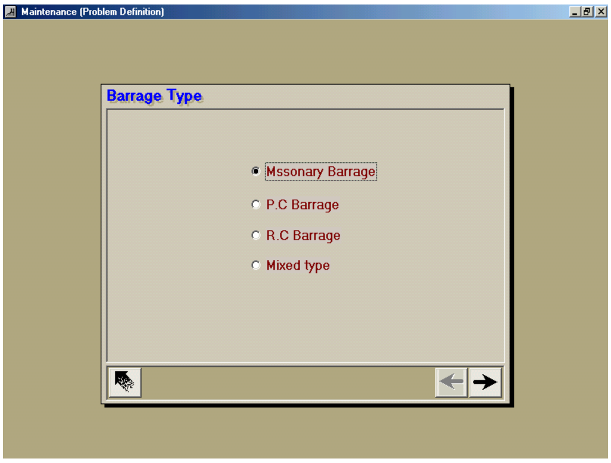

Fig. 3. First input data screen (select the barrage type)

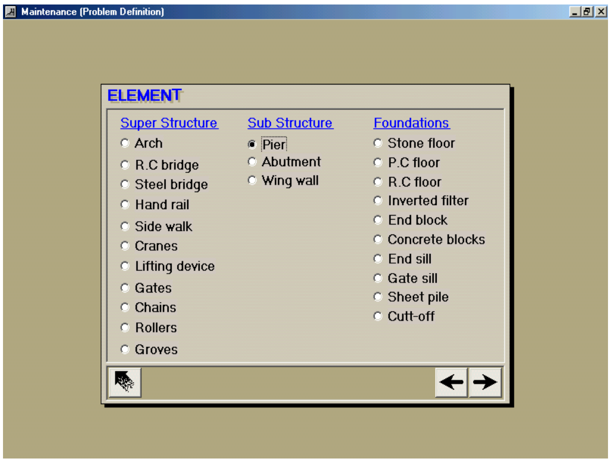

Fig. 4. Second input data screen (select the element)

Fig. 5 Third input data screen (select the material of construction)

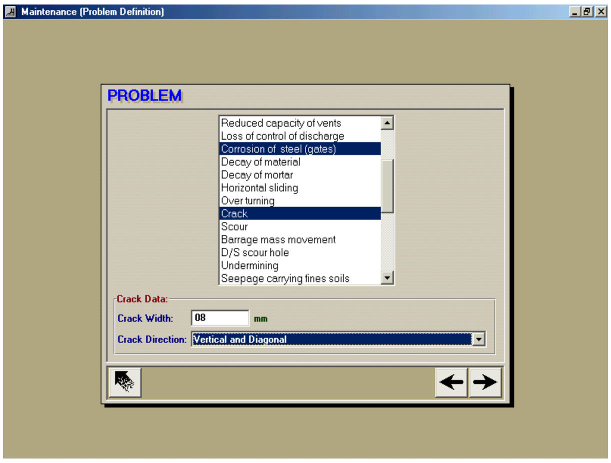

Fig. 6 Fourth input data (select the problem from list)

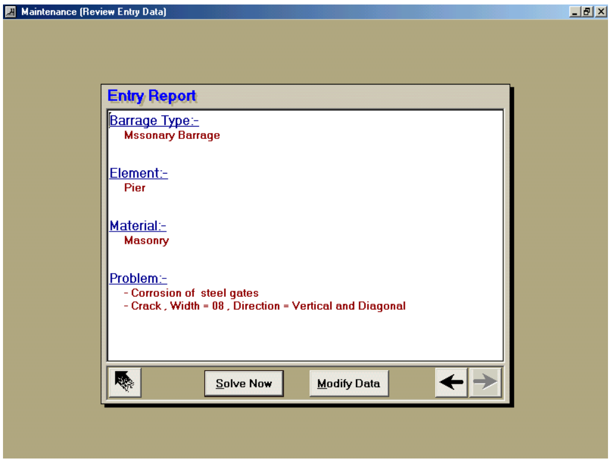

Fig. 7. Check entry data screen (modify the data or continue)

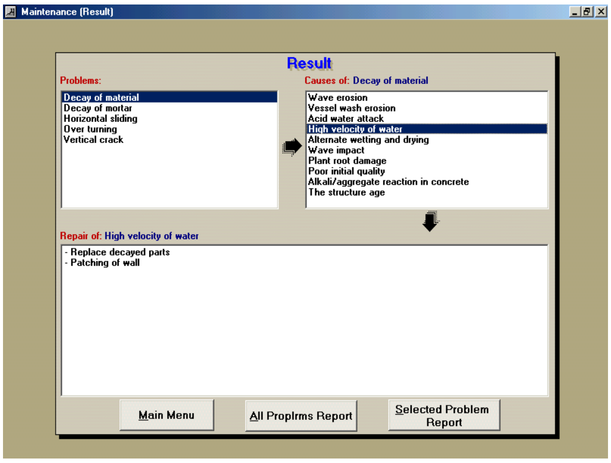

Fig. 8. Results screen (select the problem to show the causes and then select the causes to show the method of repair)

The final outcome is a report that contains the entered data and the results (causes and the proposed method of repair).

7 Validations

The proposed system has been applied to many real cases. The data for the selected problems were entered to the program, according to the sequence mentioned above and then the program identified the possible causes for such problems and suggested the suitable methods of repair. The following is a sample of the rules used in a particular case study:

► **Input data:**

- Barrage type: Masonry
- Element : Arch
- Material : Stone
- Problem : Decay of material

◄ **Output results:**

- Possible causes are:
  - Weathering
  - Thermal changes
  - Shrinkage
  - The structure age
- Method of repair is:
  - Replace decayed parts

The results of the proposed system have been compared with recommendations made by another group of experts in this field. The comparison indicated that: (i) In most problems the results of the proposed system and those recommended by the experts are identical. (ii) The results of the proposed system are arranged in the order of likelihood. (iii) The results have the same probability values as recommended by the experts. (iv) In some cases the proposed system gave different results. By analyzing the reasoning behind the results, it was found that the description of the problem entered to the system was incorrect. A good agreement was obtained between the judgments made by the experts and those achieved by the proposed system. The proposed expert system for maintenance of masonry barrages is capable of estimating the actual causes of different problems, and proposing the suitable method of repair.

8 Application of the Developed Expert System for Maintenance and Repair of Masonry Barrages

The proposed expert system was applied to a number of different problems of different masonry barrages on the River Nile, Egypt such as, Esna barrage, Naga Hammadi barrage and the Delta barrage. It was used for the assessment of the performance and safety of such structures. The data for these applications were collected from the field as well as technical reports from the Ministry of Water Resources and Irrigation (MWRI), Egypt. The proposed expert system was applied for different problems such as deterioration of stone or mortar, scour, different types of cracks, sliding, overtopping, settlement and many problems for different types of gates and mechanical parts of the barrages. The proposed system identified the possible causes for many problems and proposed different methods of repair, strengthening and replacement in some cases such as Esna and Naga Hammadi barrages which are currently being implemented. Good agreement was obtained between the proposed expert system and the experts in the field of maintenance and repair of masonry barrages. The proposed methodology is considered an efficient tool to help engineers in the field of maintenance and repair of masonry barrages in their decision making process. It also allows them to gain experience and provide fast and accurate decisions on complicated problems that require experts.

9 Conclusions

A major effort is underway to repair and rehabilitate the masonry barrages and to improve their stability as reconstruction of a large hydraulic structure such as a barrage is very expensive, when a sudden failure occurs due to lack of maintenance. As only few human experts are currently available in this field, it is important to collect the available experience and make it available for the use of engineers working in the field of maintenance. An expert system was developed for maintenance and repair of masonry barrages. The CLIPS 6.0 software was used for building the expert system and a user interface was implemented using Visual Basic 6.0. The advantages of using an expert system are that facts and rules can be easily modified to respond to changes and new rules can be added to deal with unconsidered problems. The developed expert system can help users to identify the possible causes of problems and suggest a suitable method of repair. The proposed system was verified using field data collected from MWRI for barrages on the Nile River in Egypt. The use of the proposed expert system will save time in the process of taking maintenance decisions and will help in making the expected life of the structure as long as possible. Applying expert system technology for repair of masonry barrages has many benefits such as, expertise transfer, saving the experts time, saving money, helping inexperienced users to gain some experience, providing better understanding of problems, and proving better solutions for problems.

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