Development of a knowledge-based system for condition assessment of bridges

M.S. Jaafar, Y. Yardim, Waleed A.M. Thanoon and J. Noorzaie

Condition assessment of reinforced concrete (RC) bridges is a complex subject. The complexity arises from a variety and combination of factors that define the condition of an existing bridge. A thorough condition assessment requires vast knowledge of the behaviour of RC structures subjected to different phenomena such as excessive loading, environmental effects, chemical attacks, etc. This requirement can be achieved through a comprehensive knowledge-based system, which may represent human expertise. Presently, the Public Works Department (JKR), Malaysia has a condition assessment system, which is based on visual inspection. A comprehensive system requires an input not only from visual inspection but also from that of confirmatory non-destructive tests and distress investigations, through structural analysis. This paper describes development of a comprehensive expert system that integrates the present system adopted by JKR with those of non-destructive test results and distress analysis.

The level of economic development of any country can be assessed from the extent of its road network and its quality. In the road network, the most critical and delicate points are bridges. The tragic collapse of the Silver Bridge in US on December 15, 1967, resulted in the deaths of 46 people[1]. The collapse is a very good example of new technology's problems and it led to the development of bridge inspection standards. The standards define the required qualifications of bridge inspector, the scope of bridge inspection programs, and provide standardised methods of evaluation and appraisal of bridge conditions. The condition assessment of bridge, however, requires extensive research to be conducted in the area of distressed concrete structures.

Expert systems have been defined as consulting systems that simulate the problem-solving ability of human experts through the use of expertise drawn from an information base and specific rules employed to interpret such knowledge[2]. The expert system which is used to aid in the making of recommendations, allows an expert to concentrate on more difficult aspects of the task, enforce consistency. The system would perform dangerous tasks which would otherwise be carried out by humans, and preserve valuable knowledge which would otherwise be lost when an expert is no longer available.

In Malaysia, the Public Works Department (JKR) is the custodian of over 6,650 highway bridges along the federal roads in the Peninsula and perhaps, the equal number of highway bridges along the state roads'. Many of these bridges are between 20 to 50 years old. Like other parts of the world, bridge condition assessment in the country has become very important as it helps in the maintenance aspects[4]. In the United States, the Federal Highway Administration (FHWA) indicates that expenditure stands at as much as $1 billion annually for RC bridge deck rehabilitation[1].

The efforts to find solutions to high cost of repairs are required and development of a knowledge-based system that leads to an expert system is urgently required. A good condition assessment system can help anticipate potential problems in existing bridges, where preventive actions can be taken, before structures reach a stage that requires repairs. A condition assessment process requires in-depth knowledge of the behaviour of RC bridges, awareness of changes, good understanding of design process, and, most importantly, skilled personnel. This bridge condition assessment is an expensive exercise. One possible solution to overcome this obstacle is the use of computer-assisted tools such as expert systems.

Basically, there are two major parts of an expert system, that is, the knowledge base and the inference engine. In the knowledge base, all of the expertise and general knowledge

Figure 1. Example of distress due to corrosion of reinforcement

are represented. Most knowledge bases are constructed by IF-THEN type rules. The inference engine is an algorithm or pattern recognition that an expert system performs en route to a decision. The inference engine can make inferences to decide which rules are satisfied by facts and to execute the rule with the highest priority[5]. The user interface is a mechanism with which a human can communicate with the system. There is no significant example for comprehensive expert system for bridge condition assessment for public use, however, Mikami has developed a knowledge based system for selection of the methods for retrofitting fatiue cracking in steel bridges by using an expert system shell[6]. The expert system for risk assessment of concrete dam, which has been developed by Bruno[1], can be considered as a good example of an expert system application in civil engineering area. The general structure of the system constructed in an inference tree, organises both the description of the knowledge and the procedures that control this knowledge to perform an effective risk assessment.

This research is aimed to develop an engineering decision-developing tool to assist an inspector during the inspection of potential problems associated with an existing RC bridge that may lead to the enhancement of bridge safety. The tool can clarify the problem, predict condition assessment and aid

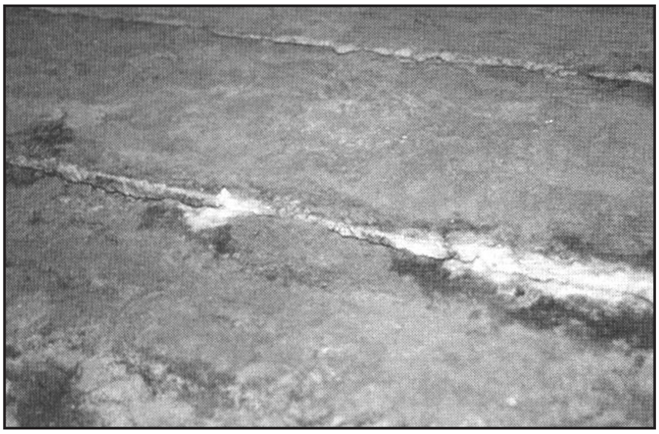

Figure 2. Example of concrete bridge deterioration due to porosity of concrete

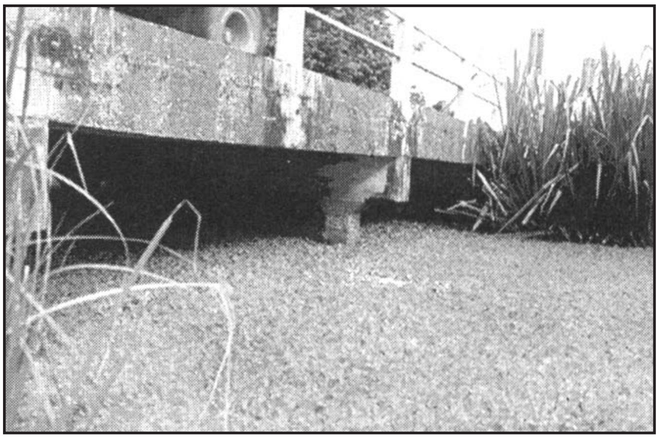

Figure 3. Example of distress due to insufficient waterway

inspector to draw a proper conclusion regarding the condition of an existing bridge.

Condition of Malaysian bridges and JKR rating system

Concrete bridges in Malaysia deteriorated at relatively young age. Some showed signs of distress when they were 15-20 years old. The distress may be prevented if continuous and proper maintenance is conducted. Some idea of the common distress can be had from Figures 1 to 3. JKR is currently putting a noble effort to ensure that concrete bridges are routinely inspected so that costly repairs and catastrophic failures may be avoided.

The JKR condition rating has been chosen as a pattern of an Expert System for Bridge Condition Assessment (ESBCA). As in JKR condition rating, bridges are rated with a combination of material and performance condition rating systems. A numerical rating system ranging from 1 to 5 is assigned to each inspected bridge component based on the observed material defects and the resulting effect on the ability to perform its intended function in the structure. JKR rating system does not have explanatory facility and has some limitation for inspection of a bridge member, although it is the popular, well known and easy to use.

The JKR rating system is well established for non-expert user but explanatory facility is quite limited and requires further improvement. At the same time, the system is not adequate for full inspection of members that have got more than one defect. For instance, consider a beam, with distress; in which, three types of damages such as crack, spalling, and corrosion of reinforcement, can be incorporated with condition as shown in Table 1. The system gives class 3 for overall rating, which is the highest rating among the three JKR ratings for the three different distresses. This rating has been given in respect of the cracking while the spalling and corrosion of reinforcement have been given rating 2 and rating 1, respectively. It is obvious that, spalling and corrosion of reinforcement decrease the overall capacity of the beam. The existing rating system does not allow for the combination of different types of distress in its rating.

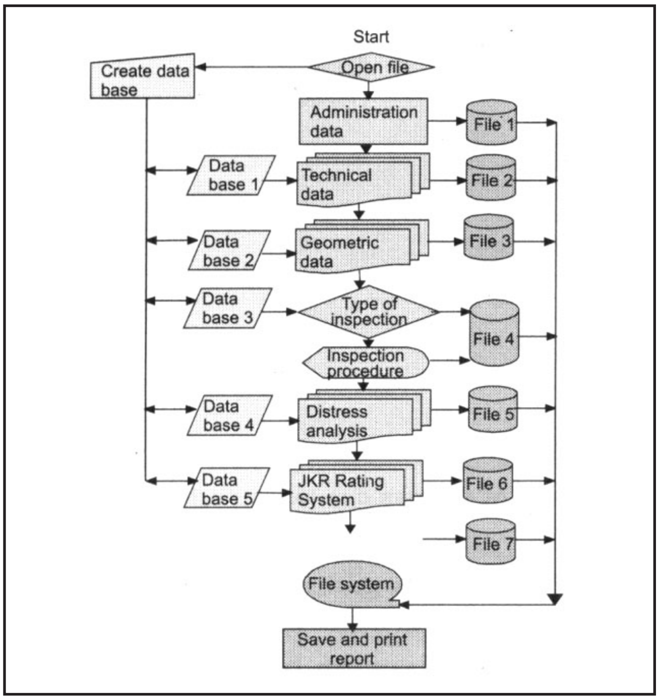

Figure 4. Architecture layout of the expert system for condition assessment of a bridge

Knowledge representation

Performing a condition assessment of bridges is essentially an information-processing task. One of the main objectives is to check the current condition of the bridge, assess the potential risk involved, and, if necessary, recommend remedial measures. The corresponding task is that of selection using heuristic classification; choosing among a series of symptoms to associate causes and effects, diagnose the corresponding failure modes, and recommend the most probable and effective remedial measures. A rule takes the form: IF (set of conditions) and THEN (set of actions) that contain certainty factors which describe the confidence of the information used in the conditions or actions, and the inference is represented by the rule itself.

To encode the large amount of general information that is a part of the background of every bridge, it is appropriate to use frame method. Frame is useful to represent descriptive information in hierarchies and contexts. It is built with a memory that can contain procedural information, details, description, pictures of bridge components and inspectors' needs.

This program guides the inspection according to JKR manual and enables the inspector to key in the bridge components in the computer so that; visibility and explanation capability of program are increased. As a result of these applications, the program compensates for lack of information about inspection and bridge components. The system provides the different probability of causes of the distress.Probability of the distress was calculated based on the "Certainty Factor Method" using a sub-expert system.

Answers expected from the expert system

The expert system processes the data collected by the user during the field inspection. These data are used as clues for the identification and classification of the following items:

1. general symptoms of distress; with reference to the JKR manual and specific mention of the certainty factor of the symptoms obtained from relevant subexpert system.

2. detailed description of distress; the expert system will provide the user with more detailed description of the distress predicted in stages. If the user provides data that is insufficient or inadequate to make a decision, the program either asks the user to provide more data, or will tell the user that confidence in the results is limited because of the inadequacy of the initial data.

Architecture of the expert system

The system architecture is presented in Figure 4. It consists of four major components that are constructed on a modular basis.

1. The database

2. The knowledge bases

3. Sub-expert system

4. Output generator.

The database system contains all the pertinent information concerning the bridge condition assessment, as well as general data on bridge. The knowledge bases contain the encoded JKR rating, domain expert, and literature for performing the inspection and making recommendation. The sub-expert system provides the probability of problem occurrences with definitions of problems. The output generator consists of a series of procedures that create a data file with the most relevant information provided about the characteristic properties of the bridge, as well as the final recommendations of the system regarding possible solutions of the problems.

Knowledge organisation

The knowledge is organised in the form of user interface, definition and introduction of bridge components, JKR rules, definition of problem, and sub-expert system.

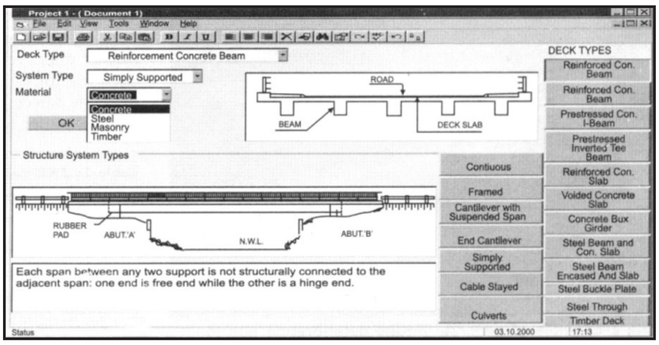

Figure 5. Database system; bridge components

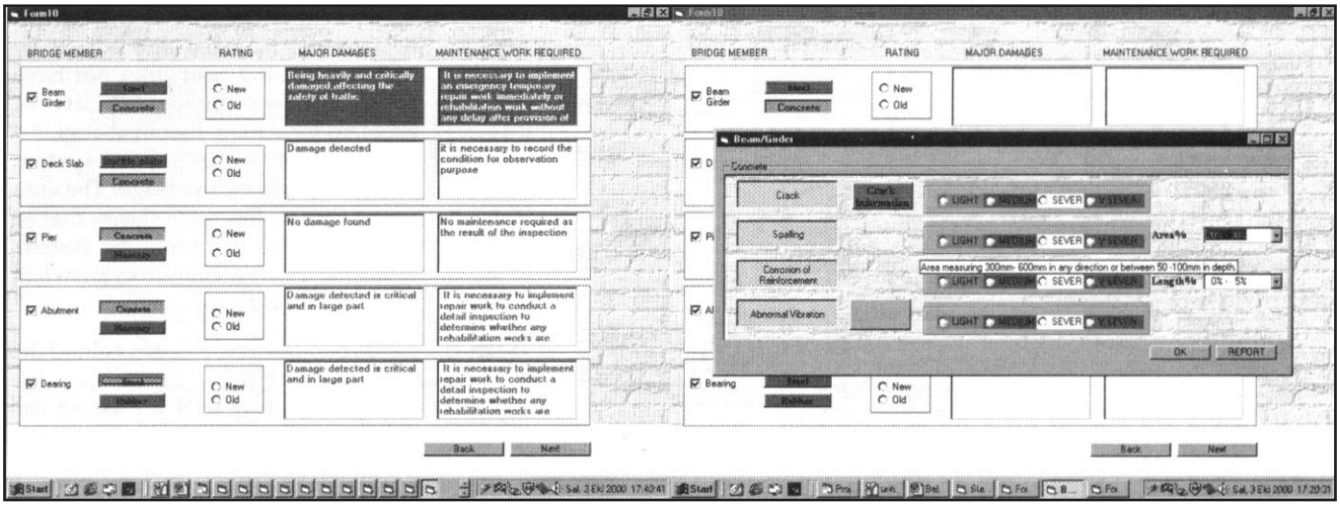

Figure 6. Knowledge base system : JKR rating

The expert system developed in this study uses some rules to represent knowledge-base system components. These rules are built up with IF-THEN statements and comprise chunks of information or knowledge encoded in symbolic form. In this manner, eventually, a set of rules is constituted. By using backward chain (from goals to sub-goals) and forward chain (from facts towards desired goals) methods, each set represents one distress type in the bridge component with a predetermined goal and sub goal. These rules are acted upon by inspector to reach the desired goal.

Application and verification of the program

To show the application and verification of the program one case study is presented. The main steps and role of components is defined below.

Data base system

The system defines each of the bridge components, as shown in Figure 5. Bridge components in the expert system evaluate users' needs and create one file which includes all components of a particular bridge that can minimise the inspection time. The system database contains all the relevant information concerning the bridge condition assessment, as well as general data on the bridge. The ability of an expert system depends on the capacity and efficiency of database. The system database has been composed by a combination of distresses, bridge members and guideline information for inspection. Main contribution of database to the whole system is shown in Figure 4. All data have been collected from literature of RC bridges and linked with knowledge base system.

Knowledge base system

The JKR codes, shown in Figure 6, are used in association with distress definition part (see Figure 7) to help coding different inspection items that assist an inspector to give much more precise assessment. Problem definitions are used to clarify the problem to enforce consistency of an inspector, which can, in turn, improve inspector consistency.

Sub-expert system

This is a system that allows the simple creation of a knowledge based expert system for concrete bridges, that is, system that behaves like a human expert, Figure 8. This system helps the inspector during the inspection to assess the probability of

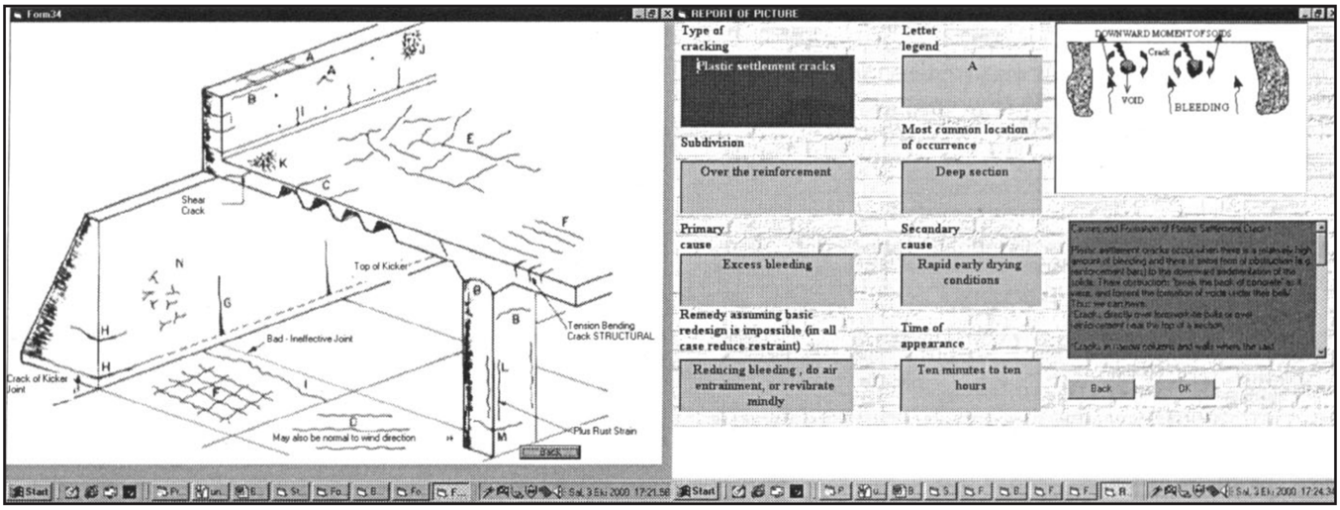

Figure 7. Knowledge base system : problem definition

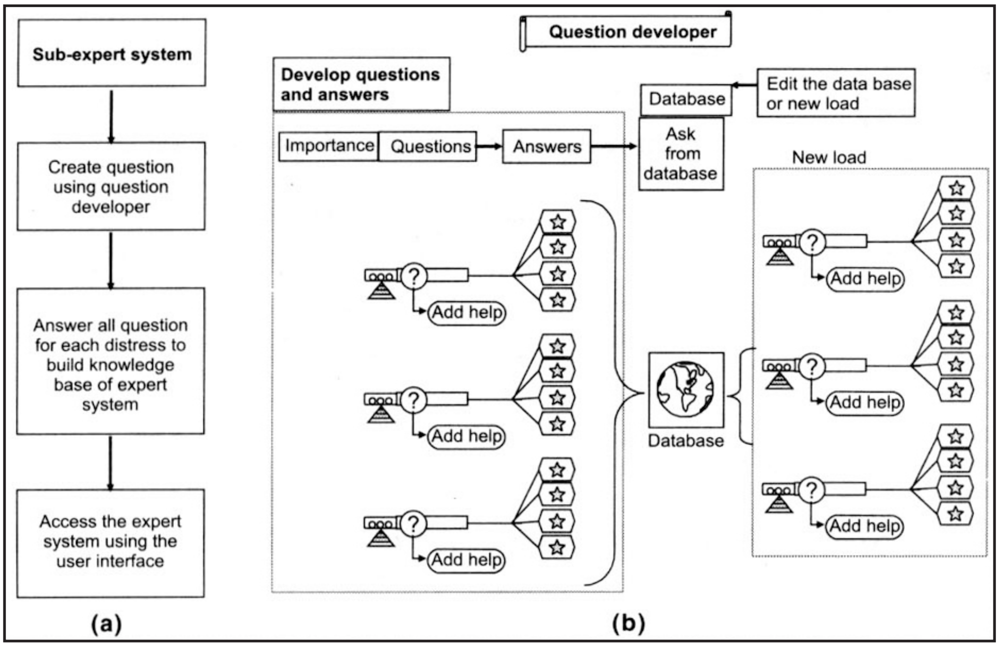

Figure 8. Sub-expert system (a) General framework (b) Steps involved

problem formation. The use of certainty factor method gives the probability of problem occurrences. The sub-expert system consists of question developers, answer settings, user interface and explanatory results.

Sub-expert system is the system that can be updated and edited by users. Thus, if a user does not have confidence in the probability of problem formation, he can change the setting of the sub-expert system according to his knowledge. The sub-expert system has three stages, that is, stages one and two build the system, while the third accesses it, as shown in Figures 8(a) and 8(b).

To demonstrate the idea behind the system, consider a crack on a RC bridge structure and let us set the system's parts according to consideration. System setting steps will be as follows:

1. prepare questions for the crack/cracks

2. figure out the possible answers for each question

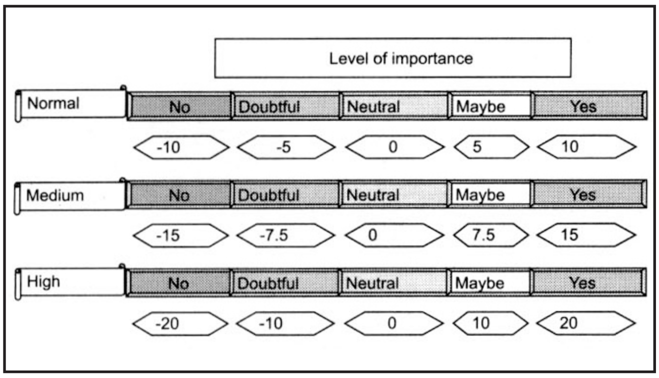

Figure 9. Importance of question

3. choose the level of importance of the questions from Figure 9

4. save setting in a question file

5. use the program.

A typical example is given below.

Step 1: Question developer for knowledge base (KB)

This part is used to develop question(s) about possible distress on a particular bridge member(s). The first step of creation KB is to decide the type of question that could be asked for particular distress and the user has to line up the questions in accordance with the levels of importance (as shown in Figure 10). The second step is to produce all possible answers for each question. The following step is to list down the causes of the distress and then create relations between answers and possible causes of distress as shown in Figure 11. This process relies heavily on the designer, as he has to take into account ideal probability of answers.

Step 2: Setting

Choose best probability of causes of distress, Figure 11, with considerations of importance and rating of all probabilities as given in Figure 12.

Step 3: Using the program

In this part, the user uses the program and gives the suitable answer for particular component of bridge, Figure 13. Sub-expert system user interface is the third and last part of the program. This part of the program integrates the question

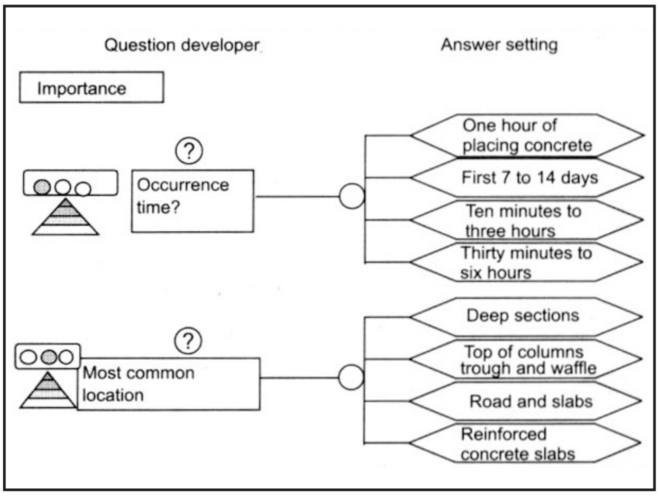

Figure 10. Scheme of question developer

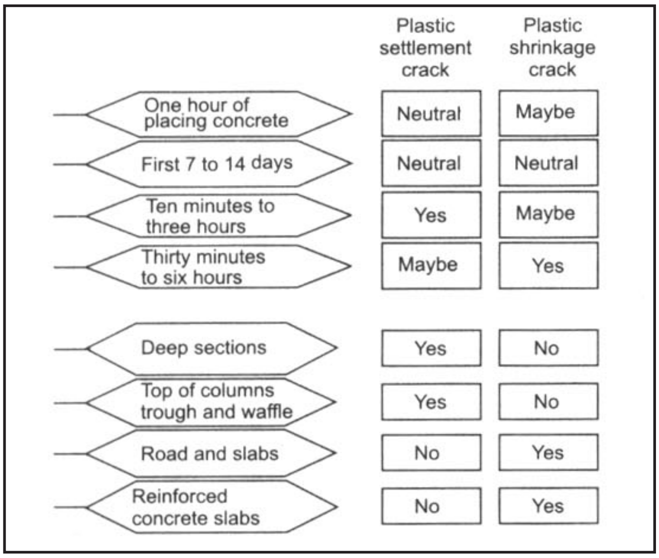

Figure 11. Setting of sub-expert system

structure, knowledge base information and input selections made by the user to ascertain the most probable solution to the given distress. In other words, sub-expert system user interface aids the user in making decisions by asking a number of questions and provide friendly interface to use program easily.

Step 4: Analysing

Program analyses the given answers with the previous setting. According to the knowledge-based (KB) information, which was set and keyed in input selection, as shown in Figure 13, and integration for each cause of distress will be as in Figure 14. From this integration, the system gets a value for each input selection according to the relation set at the KB and level of importance stage accordingly. The value of each probable range is shown in Figure 12.

Step 5: Results

This part of the program provides results of analysis as shown in Figure 15. After the integration for each question, all values which came from the input selection, are added up by the program for every single distress. This is considered the outcome value, which is out of "level of importance multiplied with number of answers", for each question. The second step for the result part, the system converts the outcomes according to its level of importance for each distress.

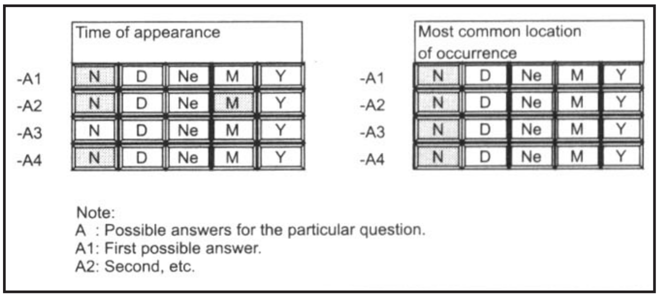

Figure 13. User's key in data

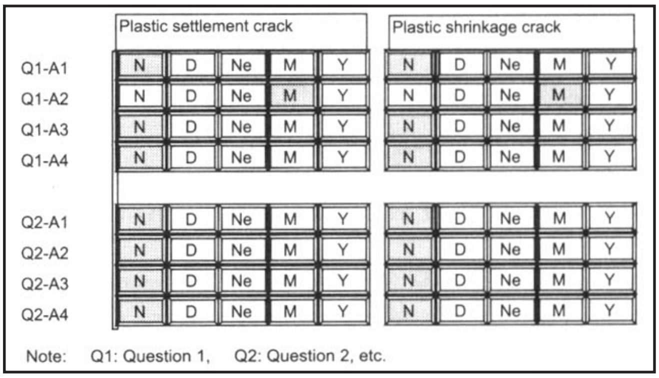

Figure 14. Analysing keyed data

File system

File systems can be used to store the related information and distress analysis which is obtained from using of the comprehensive expert system. It provides print and edit facilities for future use, Figure 16.

To assess the efficiency of the newly developed system, comparison between old and new system is believed to be necessary. In order to do that, inspection report by JKIZ on S.G. Bera bridge was used. Comparison of results is shown at Table 2. The new system includes four different type of inspection (routine, major, detailed and specific inspection). The comparison has been made by routine inspection. As a result, it can be observed that, the new system can be applied for real inspection and its final. The report is more reliable than the current system.

Conclusion

In this paper, a comprehensive expert system has been presented to perform a condition assessment of existing bridges in Malaysia. The general approach for development of the expert system is outlined, and some examples are illustrated. The end result of this research is to create an engineering decision making a tool to reduce the risk associated with the existing structures, and reduce the potential loss of life and property resulting from the failure of a bridge. The expert system processes the data collected by the user during the field inspection. This system can generally be applied to bridges in other countries,

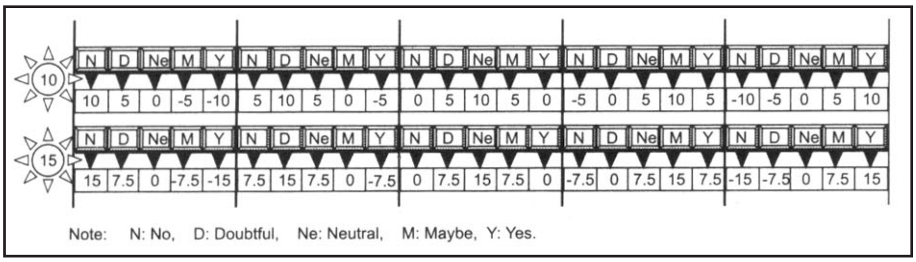

Figure 12. Importance of all possible probabilities according to relation between KB and importance question

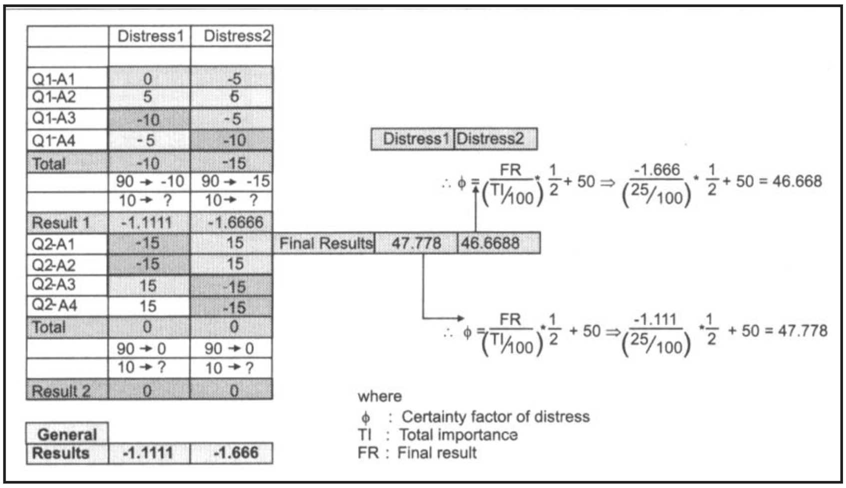

Figure 15. Results of sub-expert system

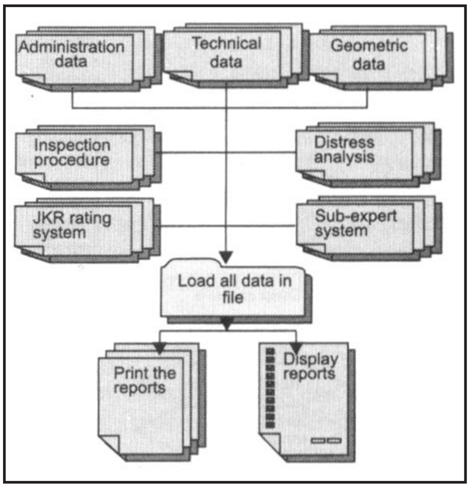

Figure 16. File system

Table 2. Comparison of new system and JKR system for S. G. Bera bridge

Member of bridge	JKR inspection result	New system inspection result
Beam/girder (concrete)	2	2
Deck slab (RC)	4	4
Abuttnent (concrete)	3	3
Pier (concrete)	2	2
Bearing	4	4
Parapet	1	1
Surfacing	3	3
Expansion joint	4	4
Drainpipes	4	4
Slope Protection	2	2

Date: 13/6/02; Structure No:_ ; Year B : 1991

including India because most distresses are common. If a specific distress is not found in this system, it can always be included by following the same format established by the system.

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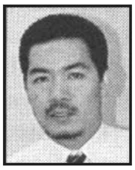

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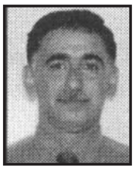

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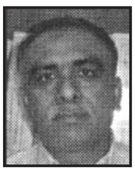

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