

## Development of Inspection System for Corrosion Crack in R.C. for Second Tunnel Lining by Using Knowledge-Based System

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### ABSTRACT

During the last two or three decades, incidence of failure of reinforced concrete structures has been seen widely for many reasons, such as increasing service loads and/or durability problems and the economic losses due to such failures are costly. Nowadays, the size and the form of repair and rehabilitation market are too large since there has been an increased emphasis on repair and retrofitting of defected structures over demolition and new construction. For safety in concrete tunnel, periodic inspection has been conducted using many testing technologies and techniques. However, these technologies cannot replace visual inspection because of their slow and complicated procedures. For this reason, the Knowledge-Based Systems (KBS) are used with lab tests results to diagnose R.C tunnel lining corrosion crack damage (DICRCTL). In this study, we attempt to propose an alternative to the human expert, to give technical decisions in diagnosing corrosion crack damages in second segment of R.C. tunnel lining. To overcome this requirement, an expert system is developed to achieve the research aim. This proposed system was constructed on a knowledge base that incorporates with the gathered information, tests in the form of rules which is suitable to implement in an expert system environment to diagnostic advisory nature. The proposed application results show an easy, fast and satisfactory answer to engineering needs.

**Keywords:** Knowledge Base System, R.C Tunnel Lining Crack Damage

### I. INTRODUCTION

In view of the fact that a large number of existing structures are being deteriorated with time by reinforcement corrosion due to environmental exposure, corrosion is one of the main causes for the limited durability of reinforced concrete (Fu and Chung, 1997).

In the recent researches and developments in science and technology, many attempts have been made to overcome the problems of people. The advancements made in the discipline of Artificial Intelligence and Computer Science and Engineering to tackled the problems related to mental and intellectual processes of the people. Gradual advancements in these disciplines have enhanced our cognitive capabilities. A knowledge-base system is a computer-based program that uses knowledge, facts and different reasoning techniques to solve problems that normally require the abilities of human experts.

In particular, serviceability and safety of existing structures need to be evaluated for a variety of reasons. Such as: Changes in use or increase of loads, new regulations with higher load requirements, effects of deterioration and damage as result of extreme loading events, unusual events (flooding, wind, earthquake, fire, bomb attack, vehicular collision, plane crash) and concern about design and construction errors and about the quality of building material and workmanship (Rucker *et al.*, 2006; Jeppsson, 2003).

The investigation process may involve a preliminary visual survey, followed by inspection that is more detailed and testing to determine the cause and general extent of deterioration. Depending on these findings, further investigation and testing may be required to identify specific boundaries of deterioration or potential deterioration. The information gathered during the investigations is used to provide understanding of the

mechanisms that cause deterioration, the severity and extent of defects and the implications for repair or other rehabilitation strategies (Jeppsson, 2003).

Farinha *et al.* (2005) established MATUF system to diagnose and repair old railway tunnels. The results obtained by the application of the MATUF system have proved their importance of using support methodologies based on ICT techniques in the field of safety control of railway tunnels.

Bartak *et al.* (2007) improved system for drill and blast tunnel construction in Taiwan by using expert system technology. The system can provide multi-expertise assistance on the decision of support system and excavation procedures to be adopted in the construction site. Also the system can provide rational estimation on the tunnel deformation under the selected support system and construction procedure with the aid of an artificial neural network approach.

Moodi (2009) proposed computer integrated knowledge-based expert systems, called SEMAREC-EXPERT, Bridge Slab-Expert and 4.T.K, to address the needs of diagnostic-related issues, identification and system knowledge users involved in repair and maintenance activities, such as condition assessment, material failure analysis, material selection and rehabilitation recommendations in concrete structures in Persian Gulf region. These programs are created to disseminate knowledge of the concrete distresses in Persian Gulf and recent advancements in concrete repair problems.

Both the inner and outer wall surface of tunnel structures are exposed to aggressive exposure conditions. The inner concrete surface is subjected to chloride-laden splash and spray originating from the abundant use of de-icing salts during winter periods and an increased level of atmospheric carbon dioxide resulting from exhaust gases. Normally, the outer concrete surface is continuously exposed to a wet environment. Especially, in coastal areas the external exposure conditions can be very aggressive as both surface water and ground water may contain significant amounts of chloride. In view of the great economical importance of tunnel structures, the severe environmental exposure conditions, the limited possibilities for inspection, maintenance and repair during service, as well as factors related to safety and serviceability, an urgent need has emerged to critically evaluate the process of reinforcement corrosion in a tunnel environment.

The splitting process of concrete cover due to the volume expansion action of corrosion products has been investigated by use of inner expanding band.

The lab test was designed to different corrosion condition which includes acceleration corrosion by using electrochemical procedure. The sample was designed as compound column to behavior like tunnel

ling segment under load condition. the duration time for acceleration was 4,6 and 8 days. The main aim to chose three duration is to get result for light corrosion condition, medium corrosion condition and heavy corrosion condition.

The proposed program (DICRCTL) asks series of questions about the concerned problem and gives appropriate advice based on its store of knowledge. The knowledge uses to make up of either rules or experience information about the behavior of segment of tunnel lining that it of a particular subject domain. Such systems can be designed for specific hardware and software configurations.

### 1.1. Inspection of Crack

Crack occurring in a concrete tunnel result from the combination of a deficiency in the repairing period, contractions due to a plunge in temperature, fluctuations between contraction and expansion caused by changes in temperature, extra loads caused by partial ground expansion, subsidence of the tunnel foundation. Cracks can be categorized as vertical, horizontal, shearing or complex. A vertical crack is linear and parallel to the central line of the tunnel arch. A horizontal crack is also linear but orthogonal to the central line.

The result of experimental program show the performed corrosion on mechanically cracked concrete specimens with crack widths in the range 0.1-1 mm depended on the duration of corrosion. They observed that, while corrosion initiated earlier the wider the crack, in all cases small.

### 1.2. Identification of Problem

General, in this study there are three results for diagnosis.

Simple crack damage, which achieved by the following criteria:

- There is no spalling and deflection or underside of arch at the R.C tunnel lining
- The cracks type is hair crack
- The strength without any reduction

Moderate crack damage, which achieved by the following criteria:

- There is spalling without any corrosion in steel
- The cracks width is near to 0.13 mm
- The small reduction in strength

Severe crack Damage, which achieved by the following criteria:

- There is spalling and deflection or underside of arch with corrosion in steel
- The width of crack is more 0.35 mm
- The strength is more reduction

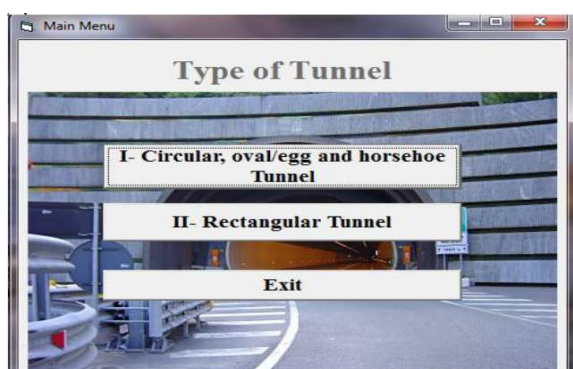


Fig. 1. DICRCTL main interface window

### 1.3. Investigation of Reinforced Concrete Tunnel Lining Deterioration

Any investigation can conveniently be split into two stages:

- Stage 1-An initial survey to identify the cause of the problems
- Stage 2-An extension of the stage 1 survey, perhaps using a limited number of techniques to identify the extent of the defects revealed by stage 1

### 1.4. Knowledge Analysis

The analysis process to the acquired knowledge has been done continuously together with acquisition process. The Fig. 1 shows the main menu for DICRCTL application. The process of the diagnosis of the damages is applied as a menu-driven and question-and-answer, the process is composed of all steps as abstracted in the data flow diagram as shown in Fig. 2.

### 1.5. Knowledge Representation

In this study, rules are used because they are the most common forms of statement in representing the knowledge. Each rule consists of one or more conditions, which, if satisfied, gives rise to one or more actions (Chan, 1996).

A rule can be expressed in the general form:

- IF (condition)
- THEN (conclusion or action)

Such rules are sometimes called “Production Rules” since they produce a result.

### 1.6. Example

IF the type of damages in the tunnel lining is “cracking” AND the cracks appear on all the sides AND the cracks are “longitudinal” AND the cracks “follow the pattern of the reinforcement” THEN CAUSES. This

flowchart starts with the main menu that includes the main types of tunnel lining to be identified. For every type of these damages there are several choices and questions from which the type of the happened damage is specified. This method begins from the conditions or events until reaching the goals.

## 2. MATERIALS AND METHODS

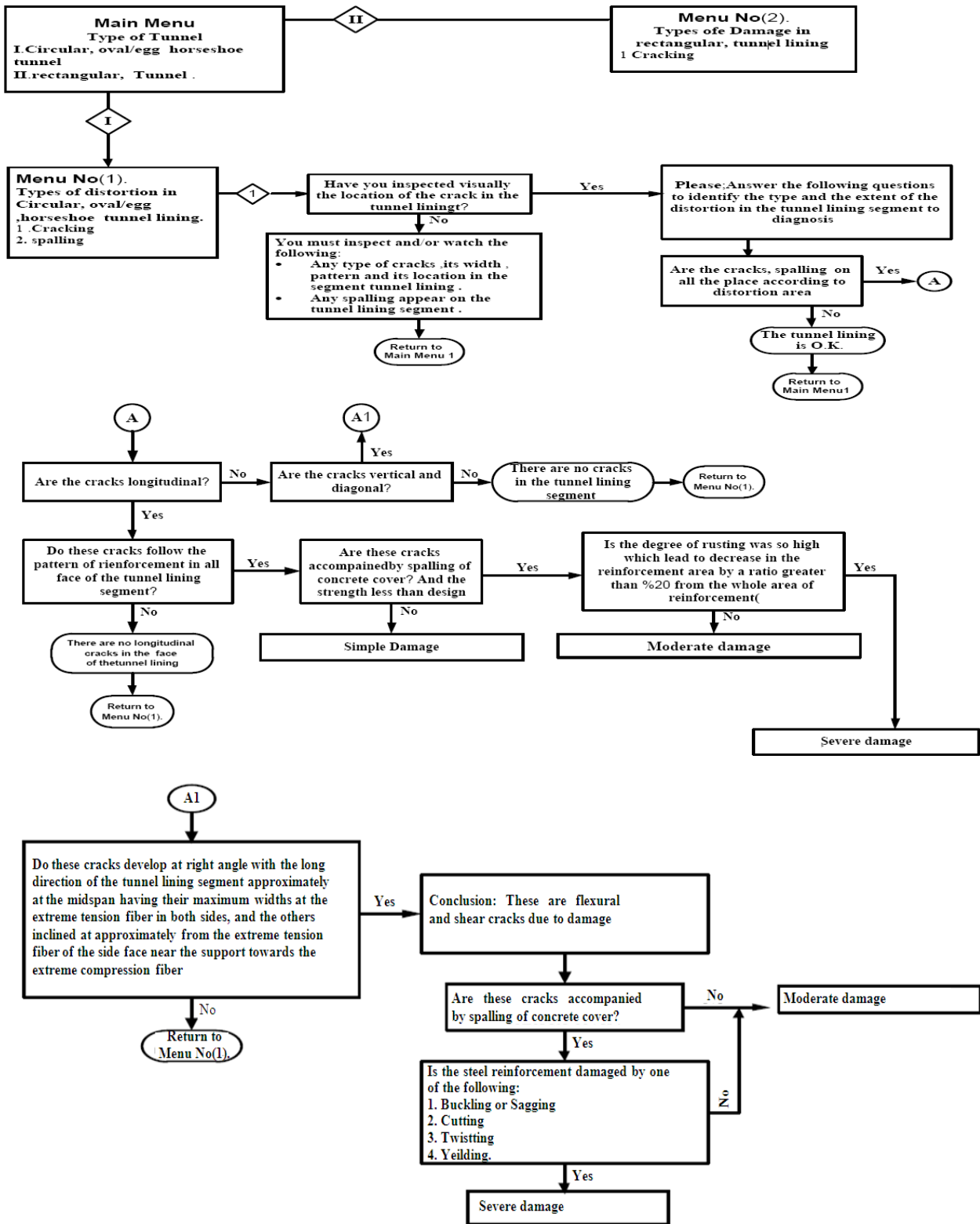
### 2.1. Experimental program

Tension compound column was used for bearing capacity test that designed to fail with tension stress (GB50010-2002). The compound column was design to bear two types of load, moment and axial load. The compound column specimen’s details were shown in Fig. 3. The concrete mixture parameter was cement, 309, sand 824gm, aggregate 1048gm and w/c = 0.45. The tests for concrete and steel were according to Chinese specification (GB50010-2002). After curing for 36 specimen, the specimens were prepared to accelerated corrosion by applying anodic current of specified intensities and for specified time periods (4 days, 6 days and 8 days). This was achieved through DC power supply with a built-in ammeter to monitor the current and a potentiometer to control the current intensity which it was equaled  $2 \text{ ma/cm}^2$ . The concrete specimens were partially immersed in 5% sodium chloride solution in a tank such that the base of the specimen was just in contact with water as shown in Fig. 4. To get the significant corrosion level (corrosion current density  $I_{\text{corr}}$ ) with time for all specimens, the Linear Polarization Resistance Measurement (LPRM) technique will be used for all specimen (Ijsseling, 1986).

The LPRM idea is constructed according to the Stern-Geary characterization of typical polarization curve for the corroding metal. In other words, if a large current is required to change the potentials by a given amount, the corrosion rate is high and on the other hand, if only a small current is required, the corrosion rate is low. For corrosion rate measure, the corrosion test electrochemical measurement system (CS) was used. The electrochemical measurement system is an integrated set of full automatic electrochemical measurement and analysis that controlled by microcomputer. The system can be used for measuring corrosion rate as shown in Fig. 5.

### 2.2. Experimental Results

The corrosion crack behavior was investigated every time period and registered the changing. The corrosion crack maps draw for each specimen group see Fig. 6. The results show the corrosion crack was longitudinal in the steel direction. The corrosion crack width for 4 days corrosion was between 0.1-0.4 mm, 0.1-0.7 mm for 6 days corrosion and 0.1-1 mm for 8 days corrosion.



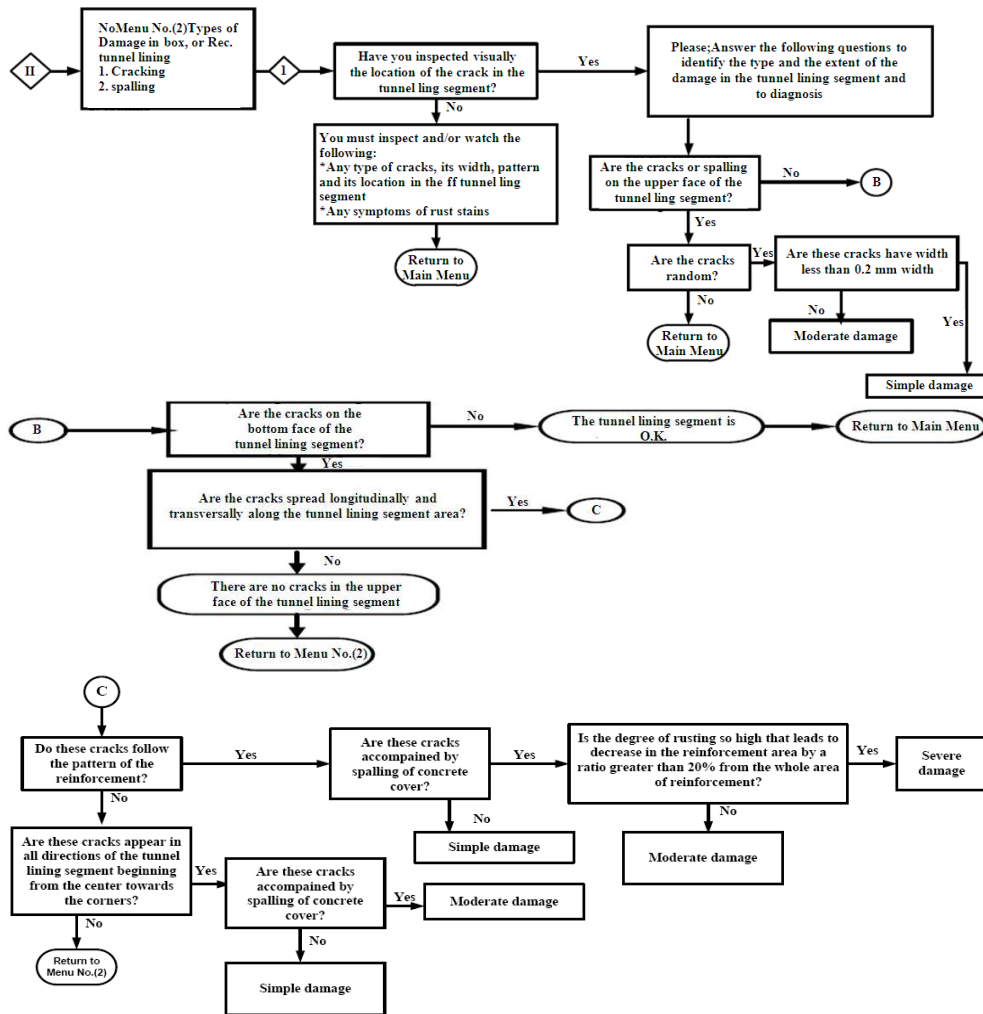
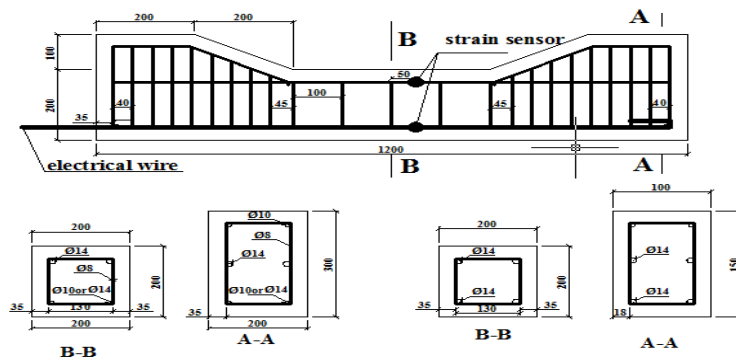


Fig. 2. The Flow Chart Described the DCDRCTL mechanism



Note : All The dimension in mm

Fig. 3. The specimen shamtic

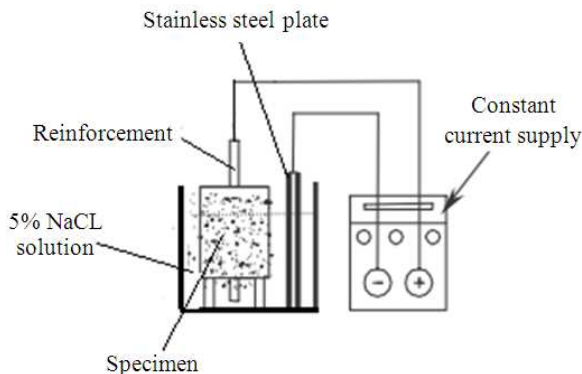


Fig. 4. The electrochemical acceleration system

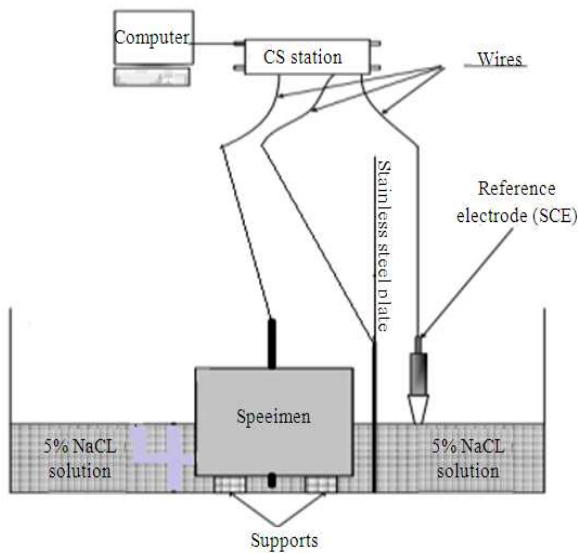


Fig. 5. The corrosion rate measure detail



Fig. 6. Corrosion crack map and bending load crack

The bearing capacity results show the crack width increase around 4% for 4 days corrosion, 6.4% for 6 days and 9% for 8 days corrosion under loading condition and in load failure.

### 3. RESULTS

The user interacts with the system through a user interface that simplifies communication and hides much of the complexity, such as the internal structure of the rule base. Knowledge system interfaces employ a variety of user styles, including question-and-answer, menu-driven, or graphics interfaces. The final decision on the interface type is a compromise between user needs and the requirements of the knowledge base and inference system. The heart of the expert system is the knowledge base, which contains the knowledge of a particular application domain. In a rule-based expert system this knowledge is presented in the form of if... then... rules. The knowledge base contains both general knowledge as well as case-specific information. The knowledge of the (DICRCTL) knowledge system is represented as tree of rules contain all questions that user may be ask it to lead to the solution. The constructed tree is the space of problem of the (DICRCTL) knowledge system. The inference engine applies the knowledge to the solution of actual problems. It is essentially an interpreter for the knowledge base. In the production system, the inference engine performs the recognize-act control cycle. The procedures that implement the control cycle are separate from the production rules themselves. In this (DICRCTL) knowledge system we considered the Expert System Lifecycle. The procedure of the execution is begun with menu-driven to select the type of the simple R.C tunnel lining such as box, circulars tunnel. After this step there are a submenu used to select the type of the damage occur in the simple R.C tunnel lining element. The next step represents the scenario and dialog between the (DICRCTL) knowledge system and the user. The scenario is done by the question-and-answer, where the expert system asks and the user answer until reach to the goal of the diagnosis.

### 4. DISCUSSION

The study was discussion, who can develop easy programe to can diagnosis the corrosion damage on second tunnel lining. The program was developed depended on the test result and previous studies.

### 5. CONCLUSION

From the present theoretical study and depending on its results the following points are concluded:

- The knowledge system (DICRCTL) developed in this work is a diagnostic advisory system, that can be used as an alternative to the human expert, to give technical decisions in diagnosing crack damages in R.C. tunnel lining segment
- The test result was so closed to the corrosion field condition
- The corrosion crack width range from 0.1mm to 1mm while the corrosion width will increase with average load 10kn/min, the width will increase in the range 2 to 9%
- The most difficult stage of KBA system development is knowledge acquisition because the effectiveness, efficiency and reliability of the developed system highly depend on the quality and quantity of its knowledge base
- The decision on the type of damage taken by the system, is a multitask process which requires the user to provide the necessary information about the condition of the structural element gathered by both visual as well as technical tests
- The using of the (DICRCTL) KBA system is easy, fast and give successful answer for engineer, because we take almost the perhaps damages in consideration.
- The development of the (DICRCTL) KBA system may be done by updating the knowledge base in the system without changing the inference engine

## 6. ACKNOWLEDGMENT

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