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A Knowledge Base System to Control Construction Problems in Rigid Highway Pavements

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Abstract: Problems that face the highway engineer in the domain of rigid highway pavements construction are almost complex and effected by different factors. Diagnosing of these problems and suggestion of suitable solutions require significant amount of engineering knowledge, which is almost difficult to be confined at all sites of construction. Therefore, construction problems in rigid highway pavements represent an excellent domain for development of a system that contains a knowledge base covers descriptions, causes, and solutions of these problems. In this paper, the knowledge isacquired from written sources in the form of textbooks, papers, journals, manuals, electronic files, and any other written references. This knowledge is documented, analysed, and represented in a form of dilated flowchart that can be used as a suitable tool to understand the problems and find the solutions. The flowchart, then, is converted to a computer program by coding the knowledge using VISUAL BASIC programming language. The developed program named KBS-CCPRP represents a knowledge base system to control construction problems in rigid highway pavements.

Key words: Knowledge base system, construction problems, rigid pavements

INTRODUCTION

Transportation in the third world countries, basically, depends on road network rather than on other facilities such as railways, marines and airways. Therefore, it is important to construct roads of high quality, both as regards smoothness of ride and durability (Robert Hennes and Martin Ekse, 1990). Highway pavements are classified into flexible and rigid. Flexible pavement includes all types of bituminous mats and in general has little beam strength. It does not distribute load over the subgrade by its flexural resistance, but depends upon the shear strength of the base and surfacing. Rigid pavements includes plain and reinforced Portland-cement concrete pavements slabs which act like any elastic floor slab except that the positions of the distributed and concentrated forces are reversed from their conventional positions in a building frame (Robert Hennes and Martin Ekse, 1990). During construction process of rigid pavements, many problems and decisions present themselves; these problems are very similar whether the concrete quantity to be laid is small or large, they range from worrying to financially catastrophic by costly repairs. In general, these problems affect the desired quality and increase the initial construction cost (Stock, 1988; Ken Newman, 1986). Moreover, novice engineer cannot overcome such problems,suggest suitable solutions, avoid their causes, and prevent same problems that may occur in the rest parts of the work. Classification and computerization of these problems, their causes, instantaneous solutions, and preventive solutions can be very helpful in control, minimize, and prevent them. This paper presents the development of a knowledge base system that can be used by the novice engineers in the sites of rigid pavement construction to control the problems facing them. Moreover, the system can be adopted as an instructional tool throughout the repeated use by interesting highway engineers.

Domain of the Study:

Many problems can occur during construction of rigid pavement such as preparation of under-layers, materials selection, concrete producing, hauling, placing, compacting, finishing, and curing. This paper concerns with problems that occur between placing time and the time of opening the road to the traffic. This involves concrete placing, spreading, compacting, finishing, texturing, jointing, curing, protecting, testing, and final

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checking. Methods of rigid pavement construction like semi-manual construction-methods to fully mechanized construction, methods by fix form paving, and slip form paving methods are involved in this study.This paper does not involve diagnosing the problems associated with concrete production and hauling to the site, as it considers that the concrete is to be supplied by ready mix plants that are provided with all information needed about the product quality. This paper, also, does not involve diagnosing the problems associated with construction and preparation of the roadbed, as the study considers that there is a ready roadbed previously constructed but that does not prevent testing the regularity of this ready roadbed due to importance of surface regularity on the performance of the concrete road.

Classification of the Domain Problems:

Through the extensive review of the specialized references and repeated analysis, the domain problems are classified depending on their forms, locations, effects, and other common features in order to be diagnosed by the inspectors visibly or depending on tests and measurement results. In addition, problems description, likely causes and solutions are stated.

Domain problems are classified into categories according to the common features and conditions, each category includes number of problems. These categories and problems are stated below:

A. Concreting under bad conditions: These are problems restricting the construction process like bad weather, machine stop, and discontinuity of concrete feeding.
B. Bleeding: Appearance of water at the surface of the plastic placed concrete at any stage of construction.
C. Cracking: These are cracks which appear at the concrete surface during plastic stage (when the concrete still fresh) or after hardening of the concrete (during curing process).
D. Joint construction problems: These are problems related to the formation of the joint groove or to the sealing of the joint.
E. Surface irregularity: Presence of spots of high or low levelsdiffers from the specified.
F. Dusting of pavement surface: Development of a fine, powdered material that easily rubs off the surface of hardened concrete.
G. Scaling of pavement surface: Hardened pavement surface scaling can lead to severe pavement abrasion.
H. Honeycomb forms: Irregular air voids appears at the extracted testing cores or at the side faces of the slab after removing the forms.
I. Tests results problems: These problems can be diagnosed during the final inspection phase depending on field or laboratory tests results and measurements.

Interaction among the problems, their descriptions, causes, and solutions is expected due to their common features and unity of the subject, but without any conflict among them.

Figure (1) illustrates the diagram of domain problems classification.

The problems of the first category (Concreting under bad conditions) their descriptions, likely causes, and possible solutions are explained in the following articles.

A. Concreting Under Bad Conditions:

Bad conditions during pavement construction process can be expected, since this process is performed outside and on wide area of different weathers, topography, environments, facilities, resources, and other features. Table (1) demonstrate the probable causes of these problems. Hot weather placement generally has conditions that are more problematic especially when ambient air temperature above 30ºC is critical (Frank McCullough and Terry Dossey, 1999; ACI 305.1-06, 2007). Cold weather can stop the concreting when the temperature is 5ºC and fall since such weather has harmful effects on the concrete (ACI 306.1-90, 2002). The concrete temperature shall be measured before placing in accordance with ASTM C1064 or AASHTOT309.
The problems can be explained in the following articles:

A1. Rapid Slump Loss:

Rapid decrease in the concrete fluidity that leads to rip or tear slab surface during finishing (ACI302.1R-04, 2004; ACI121R-04, 2004).

▪ ***Instantaneous solutions*** (ACI325.12R-02, 2002; ACI305R-99, 1999):

1. Add small quantity of extra water to the concrete in order to substitute the lost water due to evaporation during concrete hauling and placing.

2. Sprinkle the slab surface with minimum quantity of water from a fine jet in order to aid the finishing process in the extreme cases.

Table 1: Likely causes of the problems of concreting under bad conditions

Causes	Concreting under bad conditions problems							
	A1	A2	A3	A4	A5	A6	A7	A8
Hot Weather (T>=30ºC, low humidity, windy)	x	x						
Bad planning or managing of the pavement construction	x		x	x	x	x	x	
Unexpected weather changes			x	x	x	x		
Insufficient or incorrect weather information			x	x	x	x		
Low air temperature (T=<5ºC)				x				
Bad maintenance operation for the machines						x		
No maintenance record for the machines						x		
Concrete plant failure							x	
Inadequate materials at the plant site							x	
Concrete plant is far from the construction site							x	
The truck mixers fails or be restricted in a traffic jam							x	
Bad communication among site, plant, and trucks operators							x	
Instable or disturbed sub-base layer								x
Incorrect handling by unskilled staff or incorrect tools								x
The sub-base layer is not covered by membranes								x
Incorrect vibrating method or immersing vibrators deeply which mix the sub-base material by the placed concrete								x

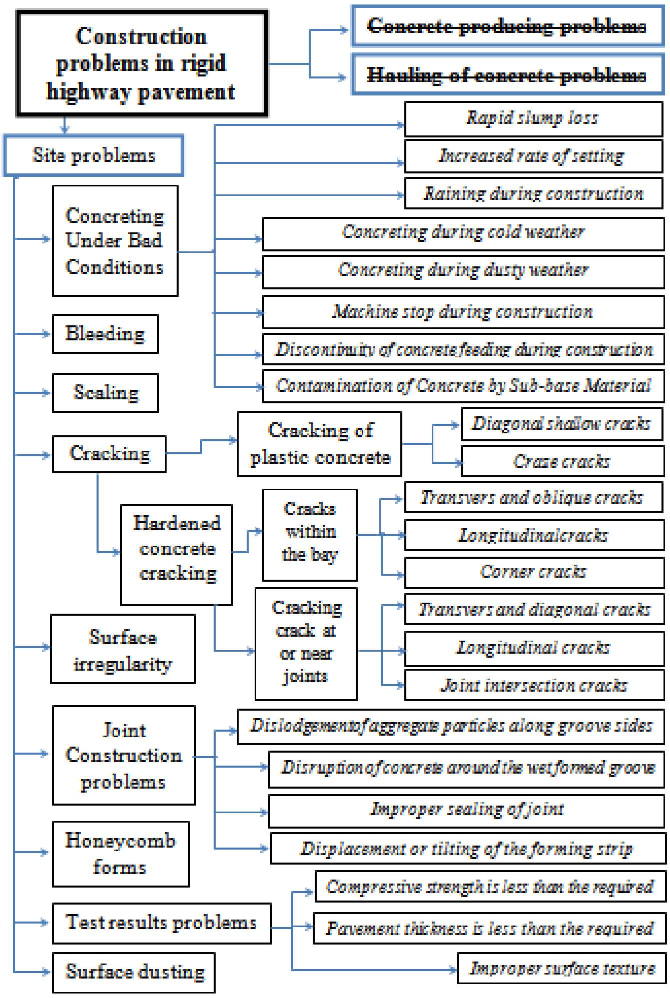


Fig. 1: Construction problems in rigid pavement diagram

▪ ***Preventive solutions*** (ACI224.1R-07, 2007; Walter and Price, 1982):
1. Supply mixtures of highest practical slump.
2. Place and finish the concrete during the coldest interval of the day as soon as delivered.
3. Shade the forms, reinforcement and subgrade or cool them with water prior to concrete placing.

4. Reduce wind velocity using windbreaks.
5. Protect the concrete with temporary coverings during any delay between concreting operations.
6. Increase the humidity at the surface by fog spraying during concreting and until curing starts.

A2. Concrete Setting Rate Increases Rapidly:

Rapid concrete stiffening leads to difficulty in concrete spreading (ACI 305.1-06, 2007).

▪ ***Instantaneous solutions*** (ACI 305.1-06, 2007; ACI305R-99, 1999):

1. Complete the concreting operation as soon as possible to avoid final setting of the concrete before finishing by increasing the labours and machinery efforts.
2. Instruct the concrete plant operators to reduce the delivered concrete to ensure stable proportioning between the delivered and placed concrete.

▪ ***Preventive solutions:***

Adopt the steps stated in article *A1* and use retarders of concrete hardening.

A3. Raining During Construction:

This problem may take place during any stage of the construction operation. Rainwater has very harmful effects on concrete since it resolves the concrete structure and eliminates its strength (Innovative Pavement Research Foundation, 2005).

▪ ***Instantaneous solutions*** (Innovative Pavement Research Foundation, 2005; ACI330R-01, 2001):

1. Stop the construction operation.
2. Inform the concrete plant operators to stop the concrete feeding.
3. Perform construction joint for the last performed part.
4. Protect the performed parts from rainwater by covering them by suitable covers. Care shall be taken to avoid distorting the concrete surface by water or covers.
5. Resume the construction operation after rain stopping or if protection arrangements (like temporary shades) are implemented to protect the concrete from the rainwater entirely.
6. Remove and reconstruct the defected parts of the pavement.

▪ ***Preventive solutions*** (Innovative Pavement Research Foundation, 2005):

1. Adopt correct and accurate weather information.
2. Adopt high-level management plan in addition to a plan for emergency cases.
3. Employ experienced staff.

A4. Concreting During Cold Weather:

This problem can appear in cold areas when the temperature is 5ºC and falling. Low temperatures can affect risky damages in the concrete structure due to freezing action (ACI 306.1-90, 2002; O'Flaharty, 1988).

▪ ***Instantaneous solutions*** (ACI 306.1-90, 2002; O'Flaharty, 1988; ACI212.3R-04, 2004):

1. In case of sudden decrease in temperature, adopt the actions of article *A3*.
2. If the concrete must be placed in cold weather the following actions can be implemented:

a) Heat the aggregate and water to moderate temperatures to make the temperature of the concrete between 10ºC and 25ºC prior to placing.
b) Produce concrete using rapid-hardening cement.
c) Add calcium chloride to the mixture to accelerate the hydration process that produces large amount of heat and increases concrete temperature.

▪ ***Preventive solutions:***

Adopt the steps of article *A3* and use rapid-hardening Portland cement and calcium chloride to the mixture to accelerate the hydration (Innovative Pavement Research Foundation, 2005; ACI212.3R-04, 2004).

A5. Concreting During Dusty Weather:

Contamination of concrete with dust due to dusty weather that reduces strength and durability of the concrete.

- ***Instantaneous solutions*** (ACI330R-01, 2001; ACI302.1R-04, 2005):

1. In case of slight dust, the problem can be neglected.
2. In case of considerable dust that can cause significant contamination in concrete, adopt the first five steps explained in article *A3* and take additional samples from the contaminated parts to ensure their compliance to the requirements of strength and durability otherwise, these parts shall be removed and reconstructed.

- ***Preventive solutions:***

Adopt the same steps as in article *A3*.

A6. Paver Failure During Construction:

This problem may take place during concrete placing that can interrupt the construction process (ACI330R-01, 2001; ACI304R-00, 2000).

- ***Instantaneous solutions*** (ACI330R-01, 2001; ACI304R-00, 2000):

1. Stop the construction operation.
2. Inform the concrete plant operators to stop concrete feeding.
3. Perform construction joint for the last performed part.
4. Resume the construction operation when the machine is re-operated and its efficiency is ensured, or when a new machine is provided.

- ***Preventive solutions*** (ACI121R-04, 2004; Standard Specification for Urban Infrastructure, 2002):

1. Adopt periodic maintenance to the construction machines and prepare detailed report for each one.
2. Adopt high-level management plan in addition to a plan for emergency cases.
3. Employ experienced staff.

A7. Discontinuity of Concrete Feeding During Construction:

Irregular, interrupted, or discontinuous concrete delivery to the site can interrupt the construction process and lead to other problems (ACI302.1R-04, 2004; ACI302.1R-04, 2005).

- ***Instantaneous solutions*** (ACI330R-01, 2001; ACI304R-00, 2000):

1. Stop the construction operation.
2. Perform construction joint for the last performed part.
3. Contact the plant operators to solve the problem.
4. Resume the construction operation when uniform concrete feeding is provided.

- ***Preventive solutions*** (ACI304R-00, 2000; Standard Specification for Urban Infrastructure, 2002):

1. Maintain the concrete plant and the truck mixers periodically and prepare detailed report for each one.
2. Provide the site with concrete from the nearest plants.
3. Deposit sufficient materials at the plant site.
4. Provide good communication among the site, plant, and trucks operators.
5. Adopt high-level management plan in addition to a plan for emergency cases.
6. Employ experienced staff.

A8. Contamination of Concrete by Sub-base Material:

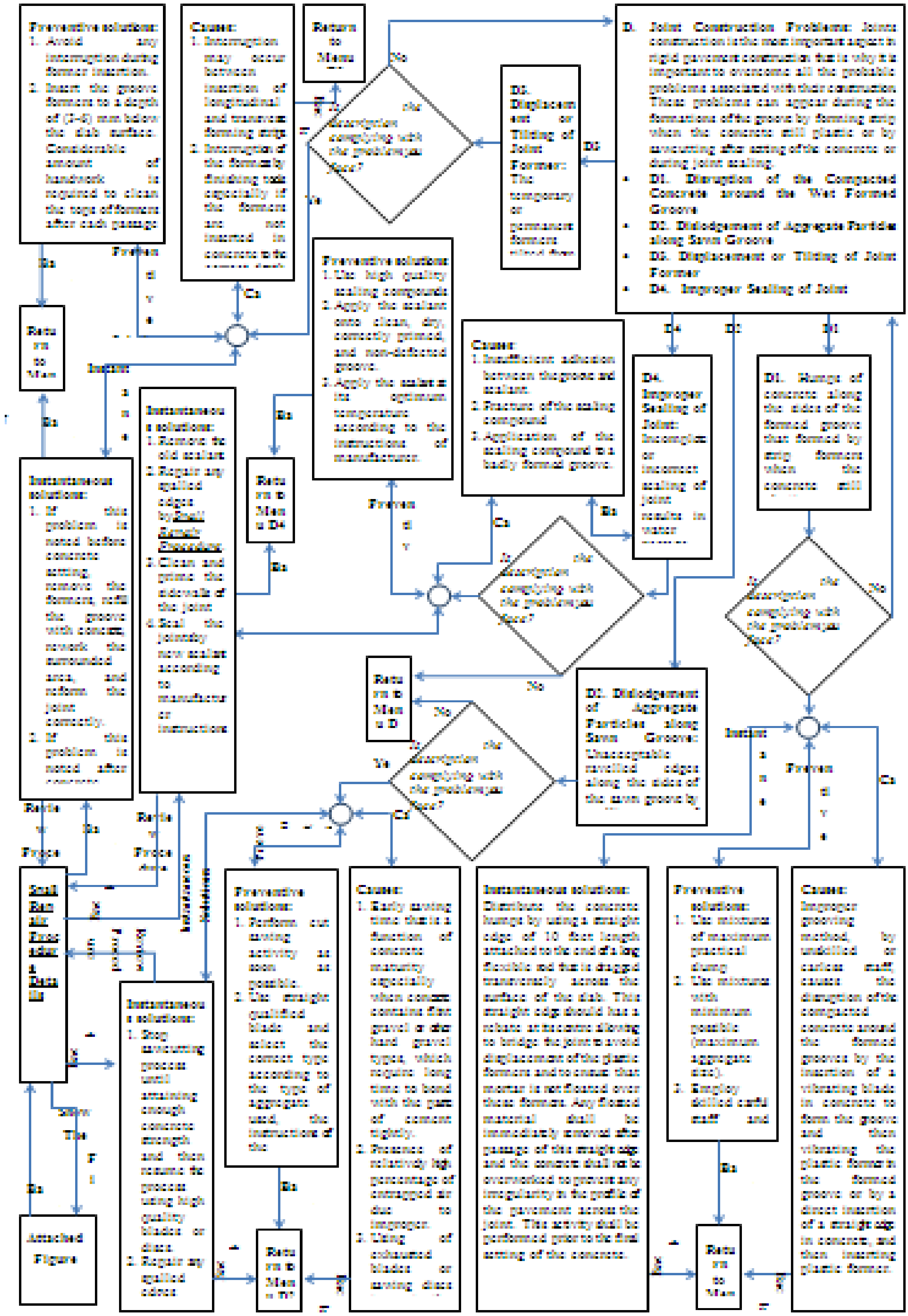
Sub-base material can contaminate the concrete during placing, compacting, or any other handling step (ACI302.1R-04, 2004; ACI302.1R-04, 2005).

- ***Instantaneous solutions:***

Remove the contaminated parts and substitute with new concrete (ACI311.4R-05, 2005).

- ***Preventive solutions*** (ACI121R-04, 2004; ACI309R-05, 2005):

1. Ensure correct preparation for the sub-base layer prior to concreting.
2. Cover the sub-base layer with membranes.
3. Employ experienced staff and proper tools (avoid garden tools).
4. Ensure correct vibration process and avoid immersing the vibrators vertically or deeply.



Fgi. 2: Concreting under bad conditions flow chart.

Building of the System:

The classified knowledge, which represents the core of the system, is prepared to be coded as a computer system through repressing it in a sophisticated flow cart. The flowchart illustrates the manner of chaining used in the developed system. This flowchart starts with the main menu that includes the main titles of the categories. Each main title leads to a brief description, thereafter, the flowchart path leads to an optional question, which leads to the main menu or the path continues forward to reach the problems in the specified category. In the same manner, the path continues until the results. This procedure in chaining, which iterates from the beginning of the flow chart to the end of it, is called forward chaining. This manner of chaining starts from the goals towards the conditions.The flow chart represents the basis to code the knowledge base in a computer environment. Figure (2) illustrates a part of the sophisticated flow chart. VISUAL BASIC programming language is used to develop the system KBS-CCPRP since it is very effective and flexible tool for development of the programs working under WINDOWS environment (Michael Halvorson, 2008). The source code version of the developed system is a multi-forms package involves 162 forms (files) that connected together in a tree structure.

Each form includes a number of commands responsible of executing specific functions in the system. The forms and the commands are named with clear expressive names that are related to the function of each command. In addition, many remarks are included in the coding menus to simplify updating process. This version (with extension of .vbp) is prepared to be used by the knowledge engineer who is responsible of developing and updating the system, an executable version (with extension of .exe) is prepared to be used by the end user who is the highway engineer, and this version is protected and unchangeable. Figure (3) illustrates the structure of KBS-CCPRP.

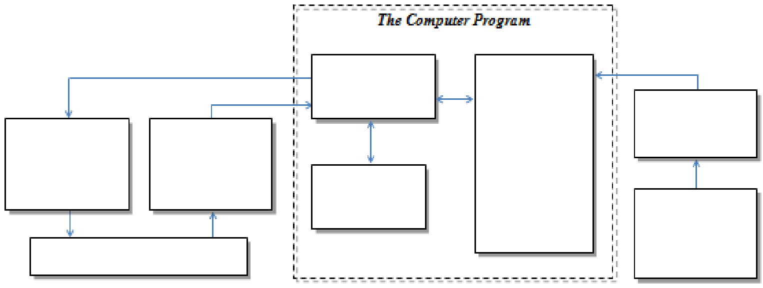


Fig. 3: KBS-CCPRP Structure

Operating and Testing of the System:

The system can be operated easily through clicking a button to execute any step using the mouse or the keyboard;the user can return to the last step anytime since, each form is provided with back button, also he can use the button (Close) to end the running of the system at any stage. Figure (4a-i) illustrates an example of KBS-CCPRP operating. The system is tested in a real environment through exposing it to operating by a number of civil engineers with different levels of experience, all of them emphasised that the KBS-CCPRP can be operated simply and friendly and it is helpful for novice engineers to overcome the domain problems.

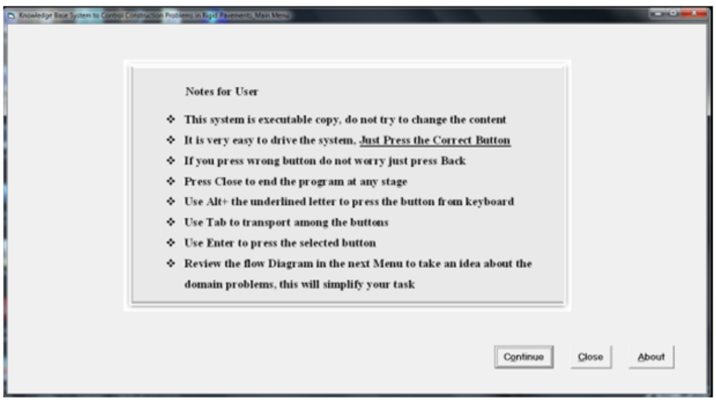


Fig. (4a): System operating. Press button to continue

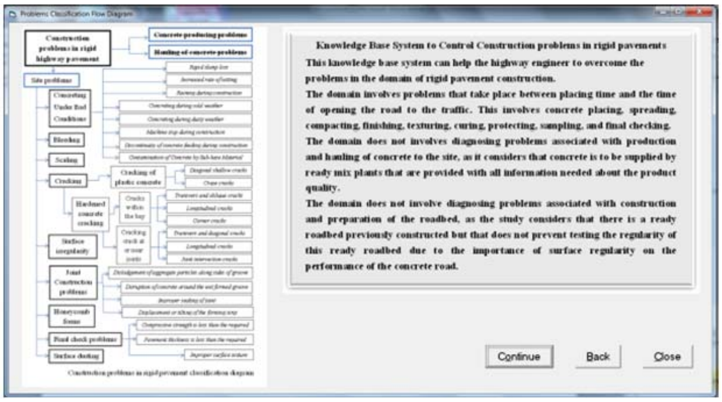


Fig. (4b): Review the flow diagram and press button to continue

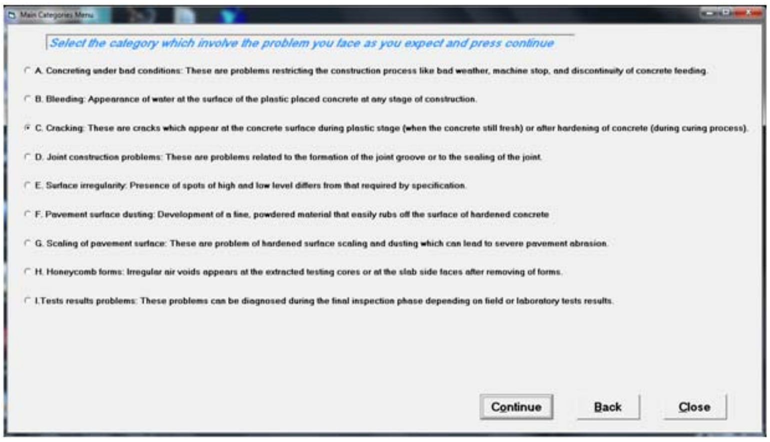


Fig. (4c): Select an option and press button to continue

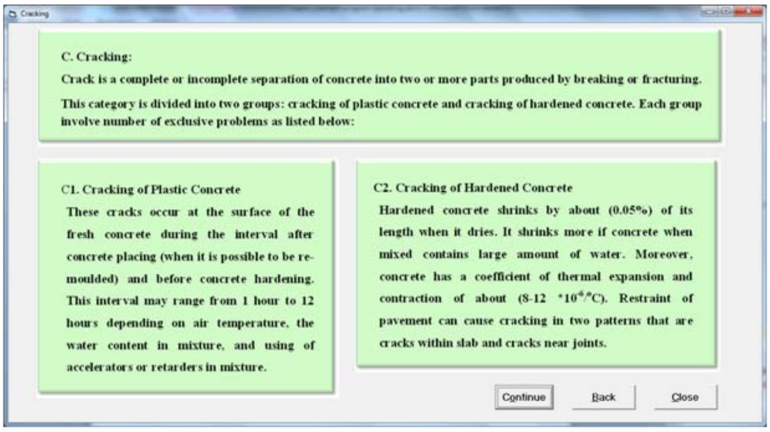


Fig. (4d): Review the menu and press button to continue

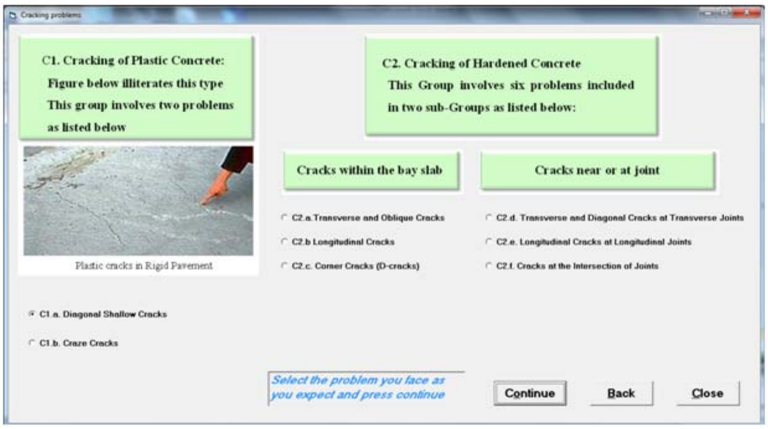


Fig. (4e): Select an option and press button to continue

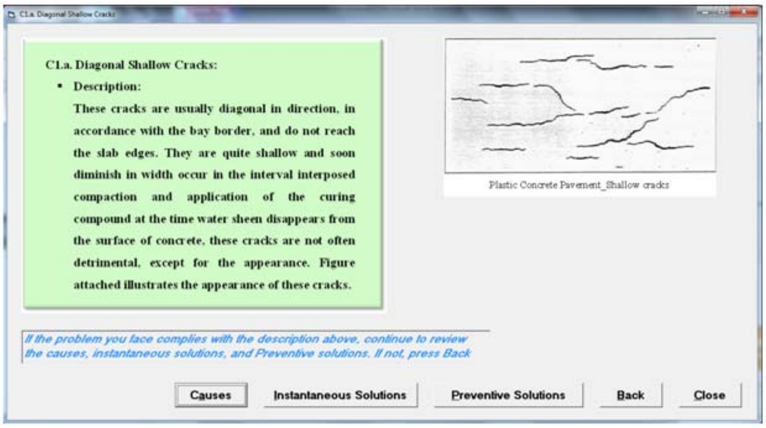


Fig. (4f): Review the description and press button to review the causes

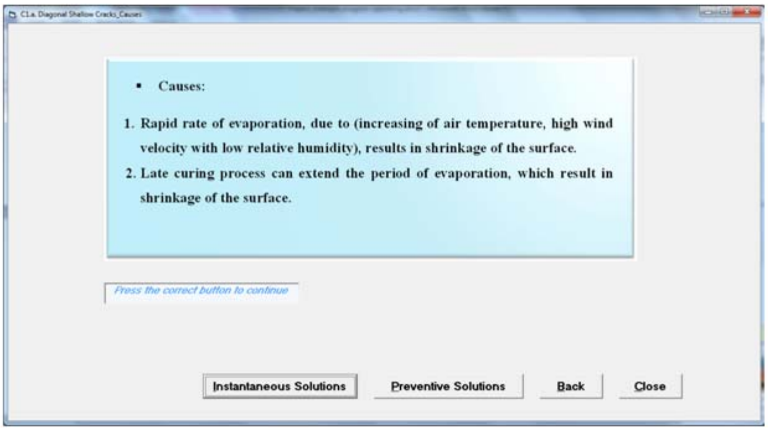


Fig. (4g): Review the causes and press button to continue

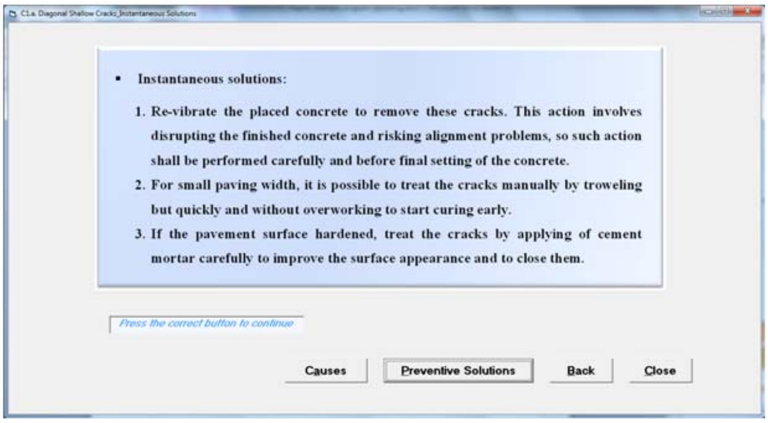


Fig. (4h): Review the instantaneous solutions and press button to continue

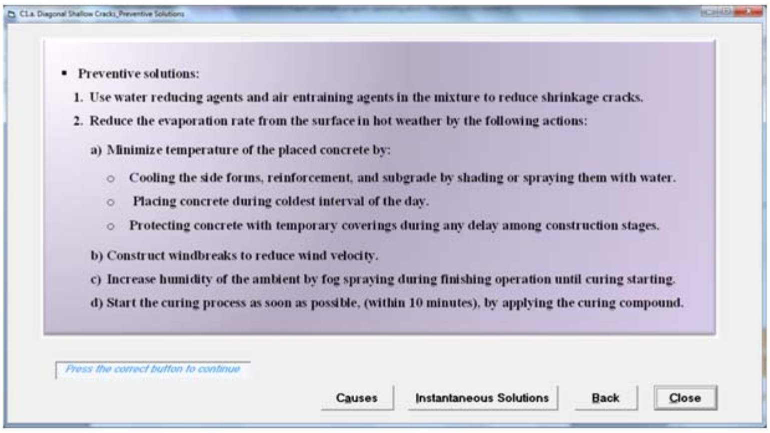


Fig. (4i): Review the preventive solutions and press back or close.

System Updating:

The system is coded by a simple manner to ensure easy updating by the developer or any other knowledge engineer in this domain who can deal with VISUAL BASIC language by feeding the system with new information continuously.

Conclusions:

KBS-CCPRP can be used by the novice engineers to overcome the problems in the field of rigid pavements construction when no senior engineers are available, this can save cost, time, and efforts, and can prevent accumulation of the problems in the site during waiting for the senior engineer. The system can be used as an instructional tool in this domain through the repeated use of it; also, it can be used as an archive to document the domain knowledge in a classified form. The system can be verified by the experts in the domain of rigid pavements and can be updated continuously by feeding it with new experiences.

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