CE 572: Computer Application in Civil Engineering

EXPERT SYSTEM FOR SELECTING BRIDGE REHABILITATION METHOD

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ABSTRACT

Bridge rehabilitation is the decision-making process for selecting and prioritizing the actions necessary to maintain a bridge within acceptable limits of safety and serviceability. The current decision-making approach for bridge management is based on optimizing the life cycle cost of the structure. This is a single criterion decision-making process which does not include the indirect impact of the maintenance, repair and replacement actions. Sound bridge management decisions should be made through balanced consideration of multiple and conflicting criteria. This requirement motivated the development of a multi-criteria decision support method for bridge deck management. The method is based on a modified analytic hierarchy process (AHP) to evaluate and rank alternative bridge rehabilitation strategies. The modified AHP provides an effective analytical tool to deal with complex decision making and has the following features: (1) multi-criteria decision-making process; (2) accounts for the uncertainty associated with the pairwise comparison values; and (3) provides a sensitive evaluation of consistency in judgements. The proposed decision support method is a rational decision-making technique for bridge management. The method practicality and validity is demonstrated using a real case study from the industry.

Key Words: Expert system, Bridge rehabilitation, Structural.

EXPERT SYSTEM FOR SELECTING BRIDGE REHABILITATION

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1. INTRODUCTION

1.1 Definition of Bridges

- Bridge is a structure having a length at least equal to 6 m, built to span a valley, road, body of water, or other physical obstacle, for the purpose of providing passage over the obstacle. Small under-ground openings are designed as culverts. [1]
- Bridges often influence the development of cultures and environments, aiding commerce, social life and urban development.
- Bridges are key elements in the transportation network because they control both the volume and weight of the traffic carried by the transportation system.
- Bridges are expensive: The typical cost per kilometer of a bridge is many times that of the approach roads to the bridge.

1.2 Bridge Types

- Bridges can be classified in different ways, according to:
  - Function.
  - Span Length.
  - Structural System.
  - Structural Material.
  - Superstructure-to-substructure connection.
  - Geometry. [1]

- Classification according to structural system:
  - Slab.
  - Beam/girder.
  - Truss.

- Rigid frame.
- Cantilever (beam/girder or truss).
- Arch (frame or truss).
- Suspension.
- Cable stayed.
- Stress Ribbon. [1]

1.3 Bridge Components

A bridge components are: -

- Substructure
  - Abutments.
  - Piers.
  - Foundation (piles, isolated).
- Bearings

Bearings may be classified as fixed bearings and expansion bearings.

- Superstructure
  - Bridge deck.
  - Girders. [1]

2. LITERATURE REVIEWS

2.1 Abstract

The prototype of the expert system was developed to help the inspector during inspections and to provide expert knowledge in all decision-making. To do this, the system has two computer modules: - bridge 1 & bridge 2.

BRIDGE-1 which is to be used in a portable computer at the bridge site. This module helps to rationalize periodic inspections, providing the inspector with useful information connected with the defects that have been found and preparing provisional inspection reports.

2.2 Inspection Methodology with BRIDGE-1

The Classification System to standardize the procedures at the inspection site, a defect classification system was prepared for BRIDGE-1. All the defects liable to be found in concrete bridges (totaling 94 entrances) were classified according to a geographical / functional / materials criteria in the following groups [13]:

- A-A. SUPERSTRUCTURE GLOBAL BEHAVIOUR (4).
- A-B. FOUNDATIONS / ABUTMENTS / EMBANKMENTS (9).
- A-C. CONCRETE ELEMENTS (13).
- A-D. REINFORCEMENT / CABLES (10).
- A-E. BEARINGS (14).
- A-F. JOINTS (11).
- A-G. WEARING SURFACE (ASPHALT) / WATERTIGHTNESS (11).
- A-H. WATER DRAINAGE (7).
- A-I. SECONDARY ELEMENTS (15).

All the possible causes (direct or indirect) of these defects (117 entrances) were then classified according to a chronological criteria in the following groups [14]:

- C-A. DESIGN ERRORS (28).
- C-B. CONSTRUCTION ERRORS (26).
- C-C. NATURAL ACCIDENTAL ACTIONS (10).
- C-D. MAN-CAUSED ACCIDENTAL ACTIONS (6).
- C-E. ENVIRONMENTAL ACTIONS (7).
- C-F. NATURAL AGGRESSIVE FACTORS (11).
- C-G. MAN-CAUSED AGGRESSIVE FACTORS (8).
- C-H. LACK OF MAINTENANCE (8).
- C-I. CHANGES FROM INITIALLY PLANNED NORMAL USE (13).

The repair techniques used to eliminate or prevent the defects listed above (69 entrances).

In the present version of BRIDGE-1, only a prototype system was developed, limited to the main reinforced concrete corrosion related defects, listed below:

- A-C01 Rust stain
- A-C07 Delamination / spalling
- A-C13 Crack over / under a bar
- A-D01 Exposed bar
- A-D04 Corroded bar
- A-D05 Bar with reduced cross-section
- A-D06 Broken bar
- A-E02 Obstruction due to rust in bearings
- A-E03 Broken retainer-bars
- A-E06 Corrosion in bearings
- A-E07 Deteriorated base plate / pot
- A-E08 Detachment / failure of anchor bolts / pins
- A-F05 Obstruction due to rust in joints
- A-F06 Corrosion in joints
- A-F07 Detachment / failure of anchorages
- A-F08 Loosening / failure of bolts / pins in joints
- A-I14 Deteriorated edge beams

2.3 Defects Rating

The rating criteria implemented in the system takes into account three basic aspects:

According to the classification presented in Table 2.1 [11], and the corresponding points are considered by the system to obtain a global rating of the defect.

CRITERIA		CLASSIFICATION	POINTS
Rehabilitation Urgency	0	immediate action required	30
	1	short-term (6 months) action required	25
	2	medium-term (15 months) action required	15
	3	long-term action required	5
Importance to the Structure's Stability	A	structural defect in main structural elements	40
	B	semi-structural defect in main or secondary structural elements	25
	C	non-structural defect	15
Volume of Traffic Affected by the Defect	α	**t.v.** x **d.l.** x **k** $\geq$ 15.000 vehicle km / day	30
	β	15.000 vehicle km / day > **t.v.** x **d.l.** x **k** $\geq$ 3.000 vehicle km / day	20
	γ	**t.v.** x **d.l.** x **k** < 3.000 vehicle km / day	10

t.v. - average daily traffic volume over the bridge (in both directions) [vehicle / day]

d.l. - detour length caused by the total disruption of the bridge [km]

k - degree of obstruction to normal traffic caused by each defect

Table 2.1 [11]

2.4 BRIDGE-2 General Architecture

BRIDGE-2 contains the bridge database and a decision system to perform the optimal strategies for management. The main submodules of the decision system are [9]: inspection strategy, maintenance/small repair and repair/ rehabilitation.

The global functionality of BRIDGE-1 and BRIDGE-2 decision systems is illustrated in *Figure 2.1* [10], to perform the inspection, maintenance and repair activities.

(BI) BRIDGE-1.

(C/D) Current or detailed.

(B2(M)) The maintenance BRIDGE-2. **(M)** Maintenance works.

B2(I) Inspection strategy submodule.

(SA) Structural assessment.

B2(R) Repair submodule.

(R) Repair work.

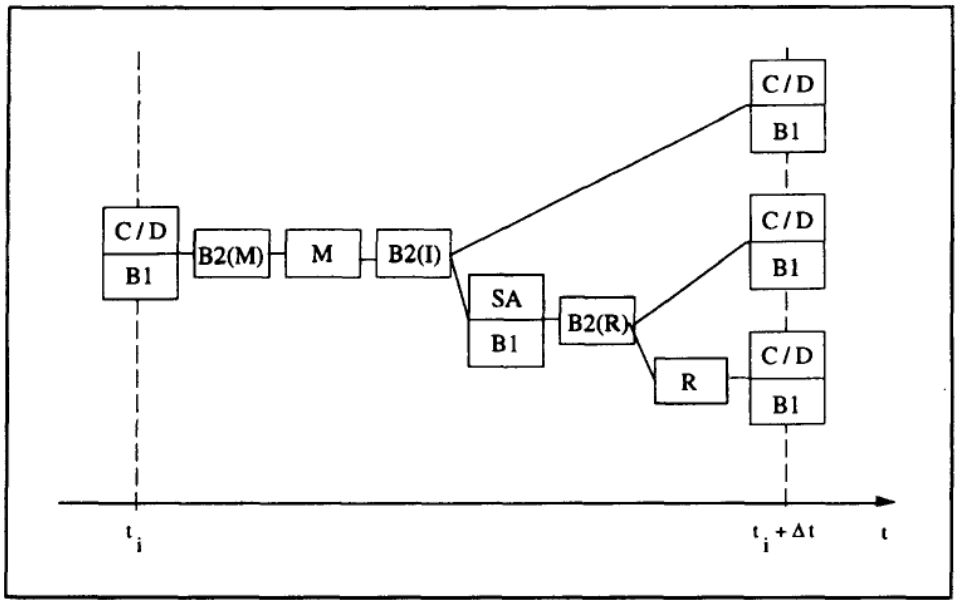


Figure 2.1: BRIDGE-2 general procedure

2.5 Maintenance Submodule

Every time a periodic inspection is performed and regardless of the possible need for a structural assessment, maintenance works must be planned and carried out before the next periodic inspection [9]. Criteria were defined, as described below, in order to choose which defects will have to be eliminated as soon as possible and which can wait until the next inspection report.

The BRIDGE-2(M) submodule offers the user the following standard main menu [16]:

(1) Rating of defects.

(2) Relevant maintenance techniques.

(3) Estimation of maintenance costs.

2.6 Repair Submodule

This submodule governs the decision to proceed with any of the repair techniques classified as structural repair work. In a broader sense, it also governs the situations in which the possibilities of upgrading (deck widening or strengthening), imposing a weight limit or replacing the bridge are considered.

The BRIDGE-2(R) submodule offers the user the following standard main menu [16]:

(1) Relevant structural repair techniques.

After a structural assessment has been performed at time T_o, a decision must be made about the bridge repair and when to perform it. For this analysis, the repair BRIDGE-2 submodule has expert knowledge (in terms of flowcharts (see *Figure 2.2* [12]*)* prepared using designers' and constructors‘ know how) to eliminate the repair techniques that are inappropriate for the defect found. The system will ask a set of questions to determine the parameters that characterize the defect and, knowing these, the possible repair methods will be pointed out. If more than one technique is considered possible.

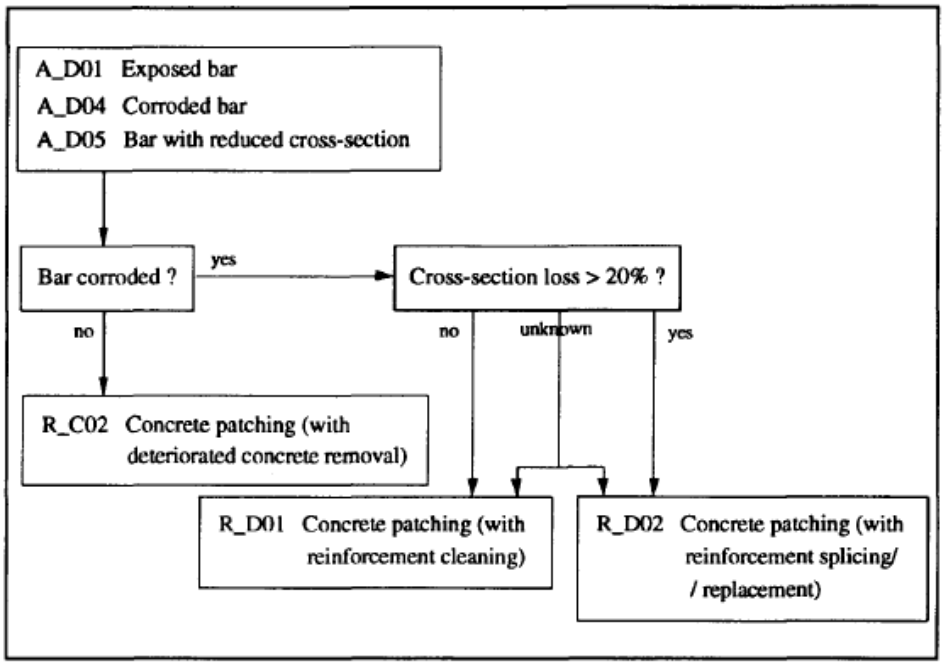


Figure 2.2: flowchart for repair technique selection

2.7 Conclusions

In this prototype, only the corrosion correlated defects in reinforced concrete bridges were implemented within the expert system, allowing for an estimation of the probability of failure, as a function of the inspection results. This leads to expert system recommendations about the necessity of performing a structural assessment and to the choice of repair technique.

The BRIDGE-1 module can be used by itself, and will soon be a very useful module for bridge inspections, as the correlation matrices for all the other defects have already been defined and will soon be implemented. The economic analysis adopted in BRIDGE-2 will also be enhanced in order to expand from the bridge domain to the network domain.

3. EXPERT SYSTEM

3.1 Definition

- In Artificial Intelligence, An expert system is a computer program that simulates the judgment and behavior of a human or an organization that has expert knowledge and experience in a particular field.
- The aim of expert system is to facilitate the work of specialists in extremely various sectors.

There is a real need to provide a tool to transfer knowledge and experience with practical guidance from Structural engineering experts and specialists to fresh practitioners and, this is the core objective of an expert system.

Proposal of a Bridge Rehabilitation is not an easy task, although experienced engineer can make it easier with deep knowledge of the common systems.

4. BRIDGE REHABILITATION METHOD DEFINITION

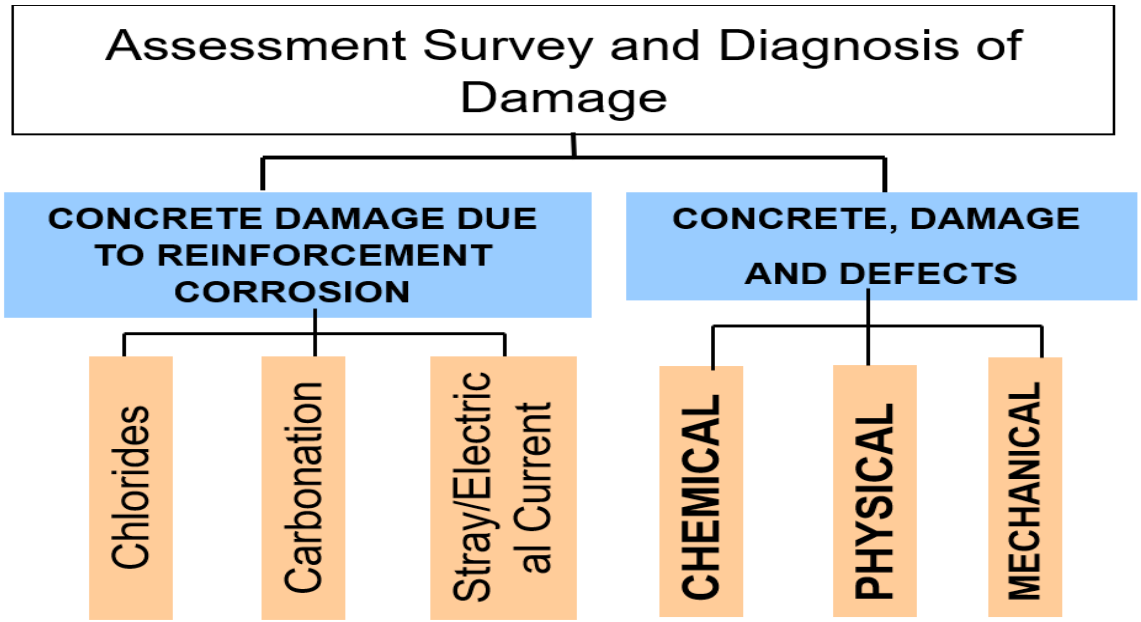
4.1 Bridge Rehabilitation

Bridge maintenance and rehabilitation can maximize the service life of a bridge and delay the need for its replacement. This will minimize the probability that these bridges will deteriorate to an unsafe or unserviceable condition. [3]

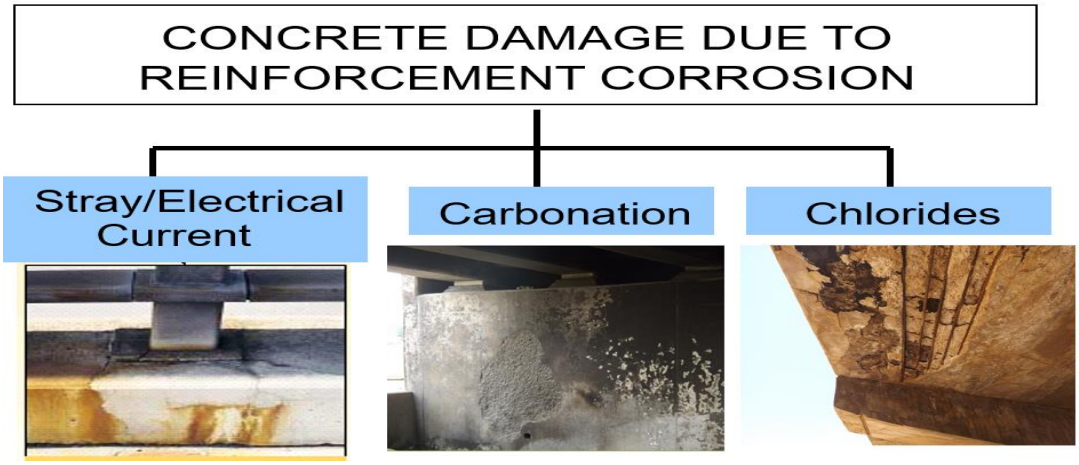
Picture of (Over Height Accidents) Picture of (Corrosion in Concrete Bridges)

5. BRIDGE CONCRETE, DAMAGE AND DEFECTS

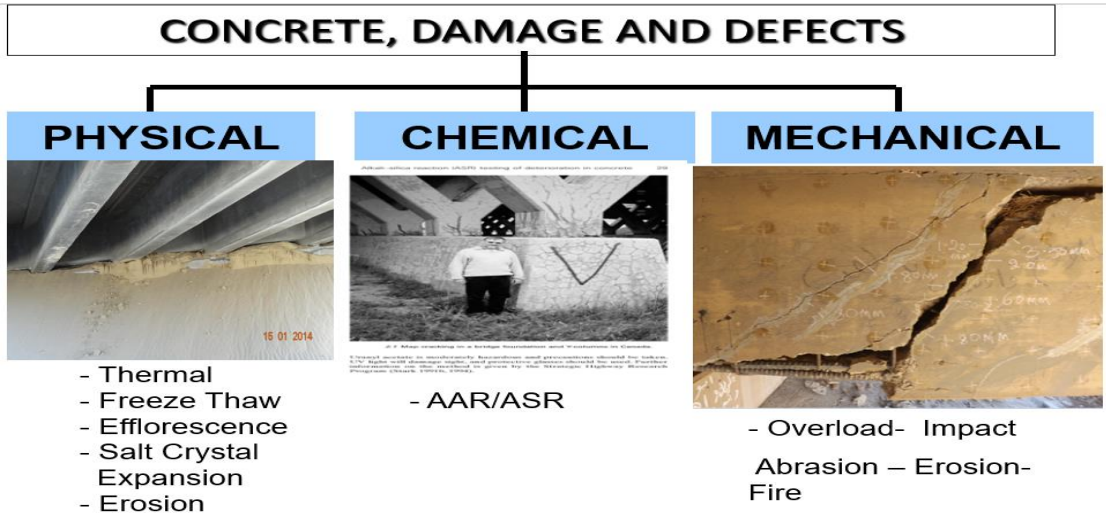
5.1 Bridge Assessment Survey and Diagnosis of Damage



5.2 Concrete Damage due to Corrosion



5.3 Concrete Damage due to Physical, Chemical & Mechanical



5.4 Bridge Damage due to Scouring

Picture of (scouring at Thumama Wadi birdge)

5.4.1 Bridge damage due to failed of joints [4]

5.4.2 Bridge damage due to failed of bearing [4]

6. DECISION – MAKING TO SELECT BRIDGE REHABILITATION METHOD

Based on the previous information about each **Bridge CONCRETE, DAMAGE AND DEFECTS** the process is adapted to select the most Bridge Rehabilitation based on the available input data.

Selection of rehabilitation type depends on (constraints):-

1-Inspection reports (visual & detailing) for Bridges.

2- Condition of bridge elements due to damage.

3- Types of repairs.

3- Cost of repairs.

4- Time of repairs.

5- Service life of elements.

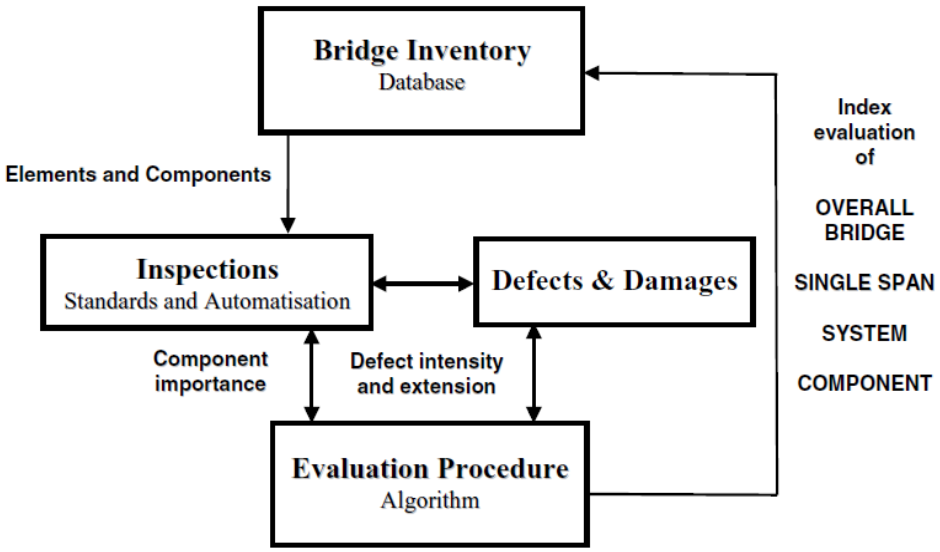


Fig. 1. Sketch diagram of the bridge condition evaluation procedure.

6.1 Types of Inspection

• **Routine Inspection**

–Superficial visual inspection every day/week/month/year.

–Basis for routine maintenance and cleaning.

–Irregular situations.

• **Principal Inspection**

–Detailed visual inspection every 1-6 years.

–Register needs for rehabilitation / special Inspection.

–Basis for medium-term budgets (5-10 years).

• **Special Inspection**

–Detailed inspection, testing, laboratory analysis, and assessment.

–Performed when required (damage cause/extent, rehabilitation strategy).

• **Monitoring**

–Continuous registration of specific properties.

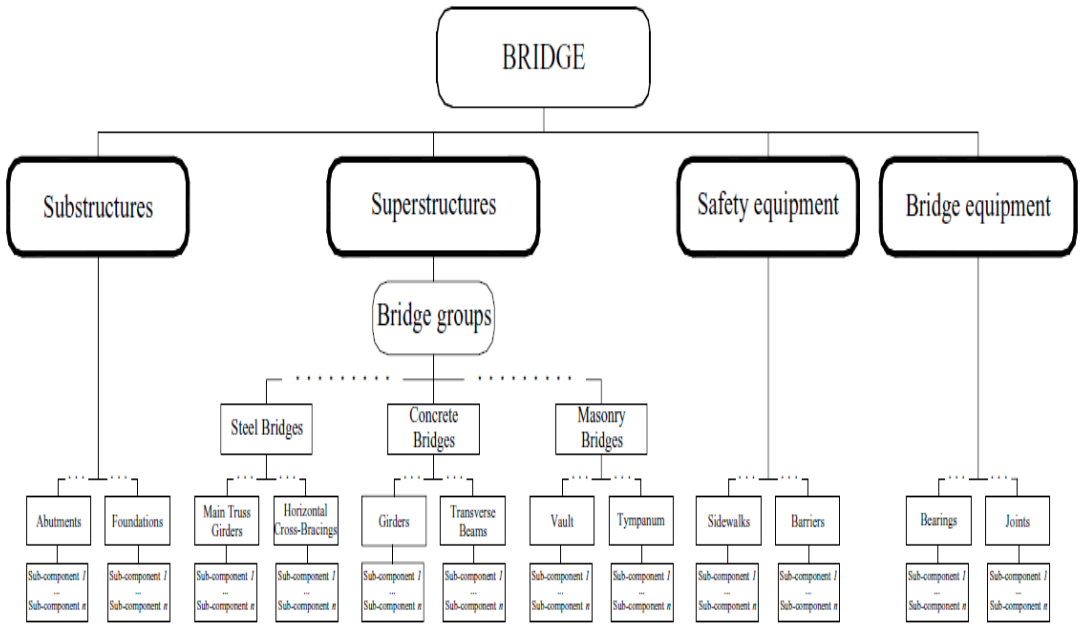


Fig. 2. Description of the bridge structure in the inventory module.

7. CONDITION OF BRIDGE ELEMENTS

7.1 Definition

- *The proper assessment of the condition of bridge elements is the cornerstone of sound bridge management. The introduction of element inspection condition methods in the early 1990s represented a significant advancement in the bridge inspection practice and has been adopted by the vast majority of all State Transportation Departments in the United States.* [5]

- Bridge Elements

1) Decks and Slabs.
2) Superstructure.
3) Bearings.
4) Substructure.
5) Joints.

Decks / Slabs (NBEs)		
El. No.	Element Name	Units
12	Reinforced Concrete Deck	AREA (SQ. m)
13	Prestressed Concrete Deck	AREA (SQ. m)
15	Prestressed Concrete Top Flange	AREA (SQ. m)
16	Reinforced Concrete Top Flange	AREA (SQ. m)
28	Steel Deck with Open Grid	AREA (SQ. m)
29	Steel Deck with Concrete Filled Grid	AREA (SQ. m)
30	Steel Deck Corrugated/Orthotropic/Etc.	AREA (SQ. m)
31	Timber Deck	AREA (SQ. m)
38	Reinforced Concrete Slab	AREA (SQ. m)
54	Timber Slab	AREA (SQ. m)
60	Other Deck	AREA (SQ. m)
65	Other Slab	AREA (SQ. m)

Table (1): Decks/Slabs

Superstructures (NBEs)		
El. No.	Element Name	Units
102	Steel Closed Web/Box Girder	LENGTH (m)
104	Prestressed Concrete Closed Web/Box Girder	LENGTH (m)
105	Reinforced Concrete Closed Web/Box Girder	LENGTH (m)
106	Other Closed Web/Box Girder	LENGTH (m)
107	Steel Open Girder/Beam	LENGTH (m)
109	Prestressed Concrete Open Girder/Beam	LENGTH (m)
110	Reinforced Concrete Open Girder/Beam	LENGTH (m)
111	Timber Open Girder/Beam	LENGTH (m)
112	Other Open Girder/Beam	LENGTH (m)
113	Steel Stringer	LENGTH (m)
115	Prestressed Concrete Stringer	LENGTH (m)
116	Reinforced Concrete Stringer	LENGTH (m)
117	Timber Stringer	LENGTH (m)
118	Other Stringer	LENGTH (m)
120	Steel Truss	LENGTH (m)
135	Timber Truss	LENGTH (m)
136	Other Truss	LENGTH (m)
141	Steel Arch	LENGTH (m)
142	Other Arch	LENGTH (m)
143	Prestressed Concrete Arch	LENGTH (m)
144	Reinforced Concrete Arch	LENGTH (m)
145	Masonry Arch	LENGTH (m)
146	Timber Arch	LENGTH (m)
147	Steel Main Cables	LENGTH (m)
148	Secondary Main Cables	EACH
149	Other Secondary Cables	EACH
152	Steel Floor Beam	LENGTH (m)
154	Prestressed Concrete Floor Beam	LENGTH (m)
155	Reinforced Concrete Floor Beam	LENGTH (m)
156	Timber Floor Beam	LENGTH (m)
157	Other Floor Beam	LENGTH (m)
161	Steel Pin and Pin and Hanger Assembly or Both	EACH
162	Steel Gusset Plate	EACH

Table (2): Superstructures

Bearings (NBEs)		
El. No.	Element Name	Units
310	Elastomeric Bearing	EACH
311	Moveable Bearing	EACH
312	Enclosed/Concealed Bearing	EACH
313	Fixed Bearing	EACH
314	Pot Bearing	EACH
315	Disk Bearing	EACH
316	Other Bearing	EACH

Table (3): Bearings

Joints (BMEs)		
El. No.	Element Name	Units
300	Strip Seal Expansion Joint	LENGTH (m)
301	Pourable Joint Seal	LENGTH (m)
302	Compression Joint Seal	LENGTH (m)
303	Assembly Joint with Seal	LENGTH (m)
304	Open Expansion Joint	LENGTH (m)
305	Assembly Joint without Seal	LENGTH (m)
306	Other Joint	LENGTH (m)

Table (4): Joints

7.2 Deck/Slab

* Decks/Slabs:-

These elements describe the component that is transferring load from the vehicle to the bridge. **[5]**

***** Description**:** This element defines all reinforced concrete bridge decks regardless of the wearing surface or protection systems used.

* Condition State Definitions:-

See the table (5).

Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Delamination/Spall/Patched Area (1080)	None	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None	Present without measurable section loss.	Present with measurable section loss, but does not warrant structural review.	
Efflorescence/Rust Staining (1120)	None	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (RC and Other) (1130)	Insignificant cracks or moderate-width cracks that have been sealed.	Unsealed moderate-width cracks or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion/Wear (PSC/RC) (1190)	No abrasion or wearing	Abrasion or wearing has exposed course aggregate but the aggregate remains secure in the concrete.	Course aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Damage (7000)	Not applicable	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Table (5): Condition state definitions of deck/slab

7.3 Superstructures

* Superstructure:-

Superstructure elements described in this section transmit load from decks into the substructure. These elements include girders, trusses, arches, and floor systems. The floor systems include floor beams and stringers. Additional elements in this group include cables, gusset plates, and pin or pin and hanger assemblies. [5]

* Description: This element defines all steel box girders or closed web girders, and is for all box girders regardless of protective system.

* Condition State Definitions: See the table (6).

Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Delamination/Spall/ Patched Area (1080)	None	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None	Present without measurable section loss.	Present with measurable section loss, but does not warrant structural review.	
Exposed Prestressing (1100)	None	Present without section loss.	Present with section loss, but does not warrant structural review.	
Cracking (PSC) (1110)	Insignificant cracks or moderate-width cracks that have been sealed.	Unsealed moderate-width cracks or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Efflorescence/Rust Staining (1120)	None	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Damage (7000)	Not applicable	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Table (6): Condition state definitions of superstructures

7.4 Substructures

* Substructure Elements:-

Substructure elements described in this section transmit the load from the superstructure into the ground. These elements include columns, piles, pile caps/footings and abutments. These elements include elements of steel, concrete, timber, masonry, and other materials. [4]

* Description: This element defines all reinforced concrete columns regardless of protective system.

*Condition State Definitions:-

See the table (7)

Reinforced Concrete - Condition State Definitions				
Defect	CS 1 - Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Delamination / Spall / Patched Area (1080)	None.	Delaminated. Spall 25 mm or less deep or 152 mm or less in diameter. Patched area that is sound.	Spall greater than 25 mm deep or greater than 152 mm diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss, but does not warrant structural review.	
Efflorescence / Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking* (1130)	Insignificant cracks or moderate width cracks that have been sealed.	Unsealed moderate width cracks or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion / Wear (1190)	No abrasion or wearing.	Abrasion or wearing has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Distortion (1900)	None.	Distortion not requiring mitigation or mitigated distortion.	Distortion that requires mitigation that has not been addressed but does not warrant structural review.	
Settlement (4000)	None.	Exists within tolerable limits or arrested with no observed structural distress.	Exceeds tolerable limits but does not warrant structural review.	
Scour (6000)	None.	Exists within tolerable limits or has been arrested with effective countermeasures.	Exceeds tolerable limits, but is less than the critical limits determined by scour evaluation and does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Table (7): Condition state definitions of substructures

7.5 Bearing

* Bearings:-

The bridge bearing are structural devices positioned between the bridge superstructure and the substructure.

* Description: -This element defines only those bridge bearings that are constructed primarily of elastomers, with or without fabric or metal reinforcement.

* Condition State Definitions:-

See the table (8).

Element #: 310 – Elastomeric Bearing

Description: This element defines only those bridge bearings that are constructed primarily of elastomers, with or without fabric or metal reinforcement.

Classification: NBE – National Bridge Element **Units of Measurement:** Each

Quantity Calculation: The quantity for this element is the sum of each bearing of this type.

Condition State Definitions

Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Corrosion (1000)	None	Freckled rust. Corrosion of the steel has initiated.	Section loss is evident or pack rust is present, but does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Connection (1020)	Connection is in place and functioning as intended.	Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended.	Missing bolts, rivets, broken welds, fasteners, or pack rust with distortion but does not warrant structural review.	
Movement (2210)	Free to move	Minor restriction	Restricted but not warranting structural review	
Alignment (2220)	Lateral and vertical alignment is as expected for the temperature conditions.	Tolerable lateral or vertical alignment that is inconsistent with the temperature conditions.	Approaching the limits of lateral or vertical alignment for the bearing but does not warrant structural review.	
Bulging, Splitting, or Tearing (2230)	None	Bulging less than 15% of the thickness	Bulging more than 15% of the thickness. Splitting or tearing. Bearing's surfaces are not parallel. Does not warrant structural review.	
Loss of Bearing Area (2240)	None	Less than 10%	10% or more but does not warrant structural review	
Damage (7000)	Not applicable	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Table (8): Condition state definitions of bearing

7.6 Joints

* Joints:-

The bridge deck joints allow a bridge to expand and Contract (movements) due to Concrete shrinkage and creep and Thermal variations. [4]

* Description: -This element defines only those joints filled with an assembly mechanism that has a seal.

* Condition State Definitions:-

See the table (9).

Defects	Condition States			
	1	2	3	4
	GOOD	FAIR	POOR	SEVERE
Leakage (2310)	None	Minimal. Minor dripping through the joint.	Moderate. More than a drip and less than free flow of water.	Free flow of water through the joint.
Seal Adhesion (2320)	Fully adhered	Adhered for more than 50% of the joint height.	Adhered 50% or less or the joint height but still some adhesion	Complete loss of adhesion
Seal Damage (2330)	None	Seal abrasion without punctures.	Punctured or ripped or partially pulled out.	Punctured completely through, pulled out, or missing
Seal Cracking (2340)	None	Surface crack	Crack that partially penetrates the seal	Crack that fully penetrates the seal.
Debris Impaction (2350)	No debris to a shallow cover of loose debris may be evident but does not affect the performance of the joint.	Partially filled with hard-packed material, but still allowing free movement.	Completely filled and impacts joint movement.	Completely filled and prevents joint movement.
Adjacent Deck or Header (2360)	Sound. No spall, delamination, or unsound patch.	Edge delamination or spall less than 1 in. deep or less than 6 in. diameter. No exposed rebar. Patched area that is sound.	Spall greater than 1 in. deep or 6 in. or greater in diameter. Delamination or unsound patched area that makes the joint loose.	Spall, delamination, unsound patched area or loose joint anchor that prevents the joint from functioning as intended.
Metal Deterioration or Damage (2370)	None	Freckled rust, metal has no cracks, or impact damage. Connection may be loose but functioning as intended.	Section loss, missing or broken fasteners, cracking of the metal or impact damage but joint still functioning.	Metal cracking, section loss, damage or connection failure that prevents the joint from functioning as intended.
Damage (7000)	Not applicable	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Table (9): Condition state definitions of joints

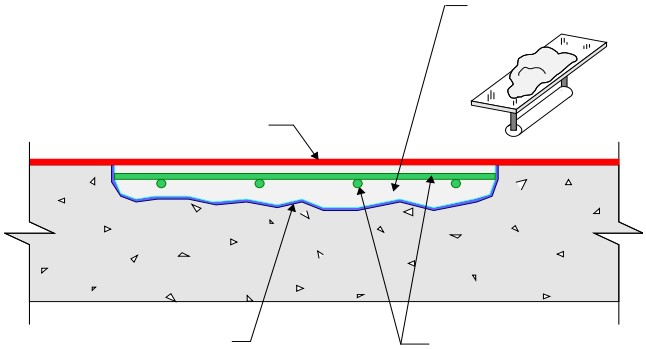
8. REPAIR METHODS

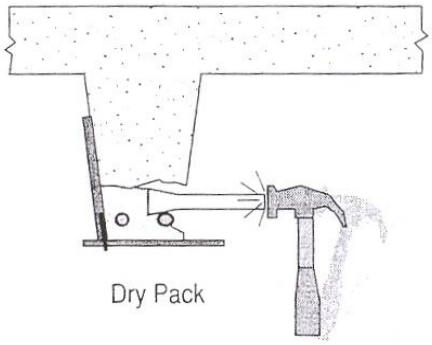
8.1 Injection (Minor Repairs)

Procedure for filling cracks and cavities under pressure with drill-hole (mechanical) or surface packers using the appropriate injection method. [5]

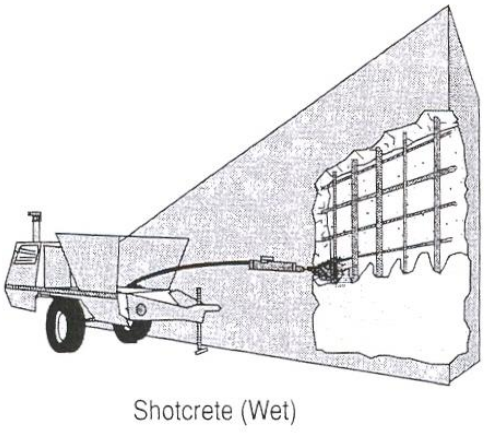
8.2 Patch Repair& Shotcrete Method (Minor Repairs)

8.2.1 Patch Repair [5]





8.2.2 Wet/dry mix spray method [5]



8.3 External Strengthening (Moderate& High Repairs) [7]

1) Plate bonding (steel, CFRP).

2) External prestressed reinforcement.

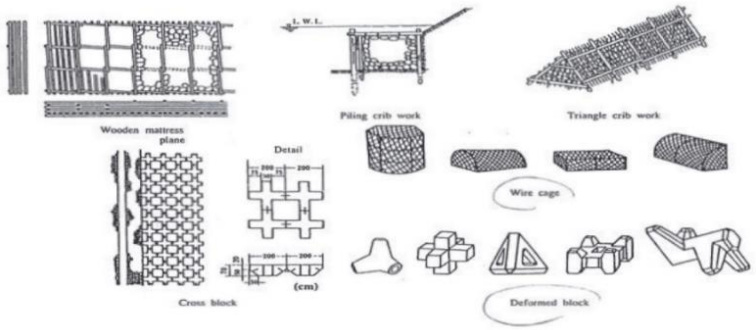
3) Bonded fabrics (carbon, glass).

4) Column Jacketing.

8.4 Other Repair (Moderate& High Repairs)

1) Scour protection. [5]

Figure IV.17. **Foot protection**



2) Reset or Replace Bearings. [7]

3) Replace expansion joints. [7]

9. KNOWLEDGE BASE OF THE EXPERT SYSTEM

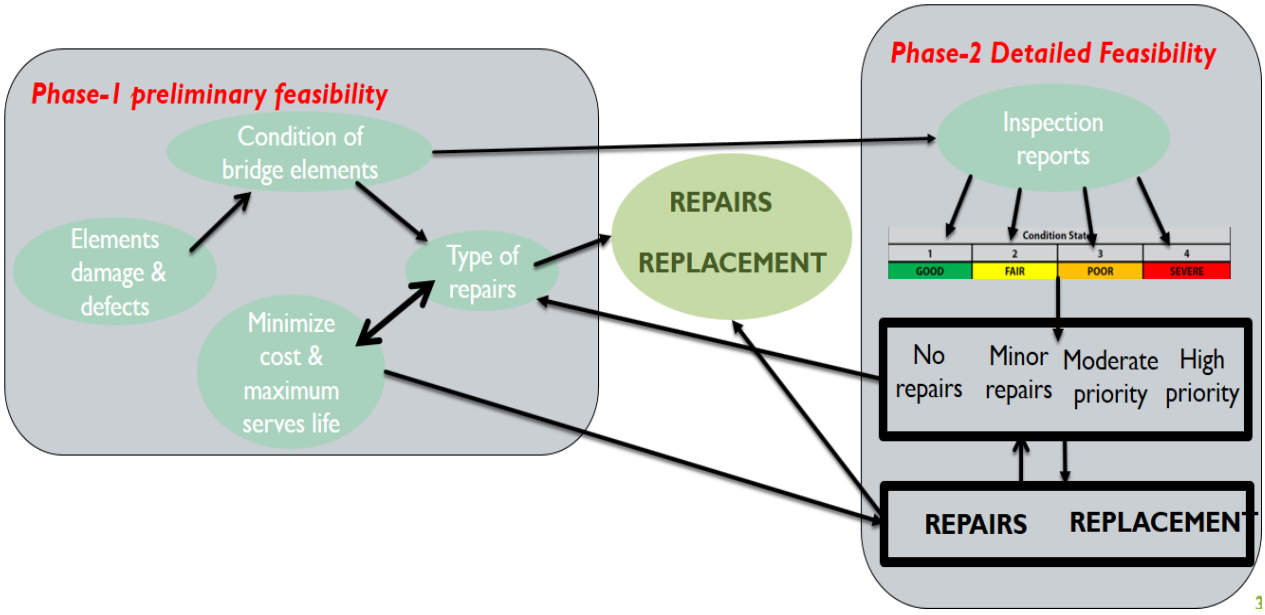
9.1 Definition

Based on the previous information about each condition of bridge elements and type of repair methods the process is adapted to select the most Bridge Rehabilitation based on the available input data.

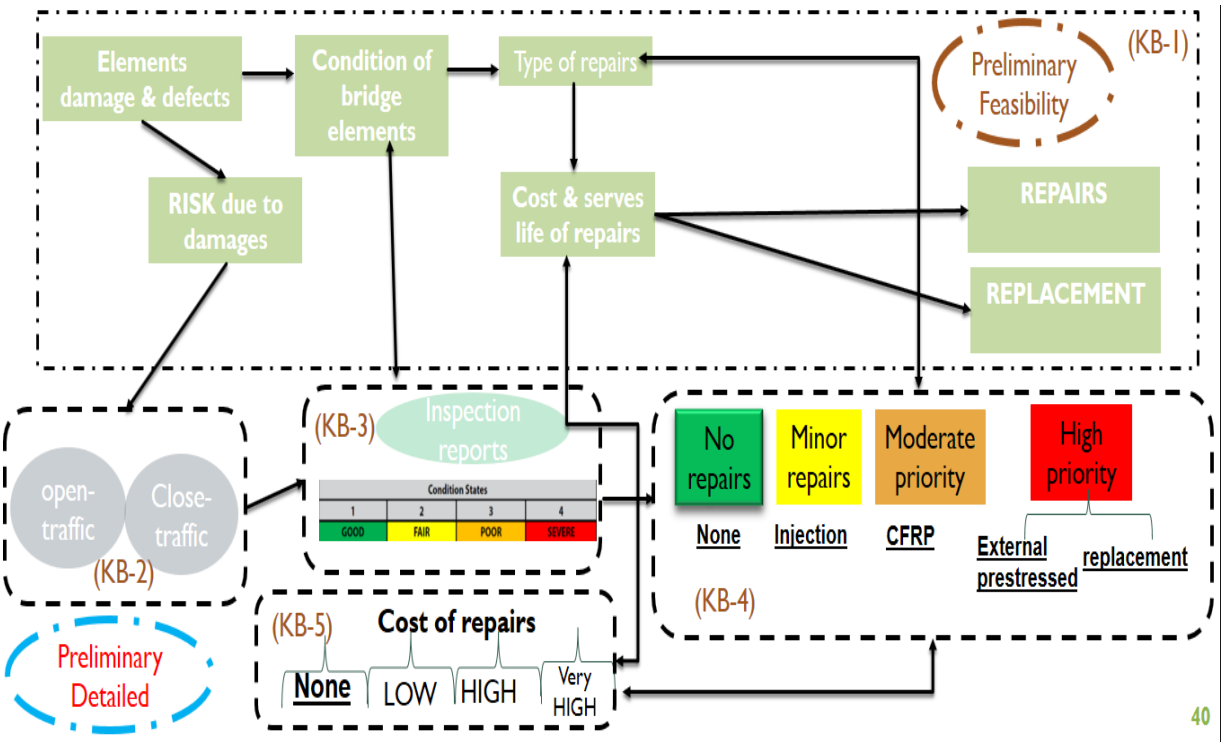
Phase-1 is dedicated for construction aspects, mainly the **Inspection reports** & **Condition of bridge elements and repair** methods as one of the most important factors that should be always taken into consideration. The next parameter is the **Cost of Repairs**, so adapting the selected bridge rehabilitation method with the Service life is much important to ensure that Time of repairs of bridges.

Phase-2 deals with details within the selected rehabilitation method, using **Specific System** as per the given parameters of the selected repair, which will provide very accurate convenient bridge elements rehabilitation method.

9.2 Sketch of Components of each Phases



9.3 Knowledge Base Organization of Bridge Rehabilitation



9.4 Expert System Implementation for (GIRDERS)[6]

The following example of the general form if a rule that has the control Bridge Rehabilitation embedded in it:

RULE: Select “External prestress”

IF The Condition of Girder-Post tension is (severe)

AND Strand Damage less than “25% from total number of strands”

AND the Cost of repair versus replacement “the cost of repair less than 70% of the replacement”

AND the Girder Displacements “The bottom flange is displaced horizontally position less than ½″ per 10′ of girder length.”

THEN select the repair of girder system “External prestress”

The following example of the general form if a rule that has the control Bridge Rehabilitation embedded in it:

RULE: Select “Replacement girder”

IF The Condition of Girder-Post tension is (severe)

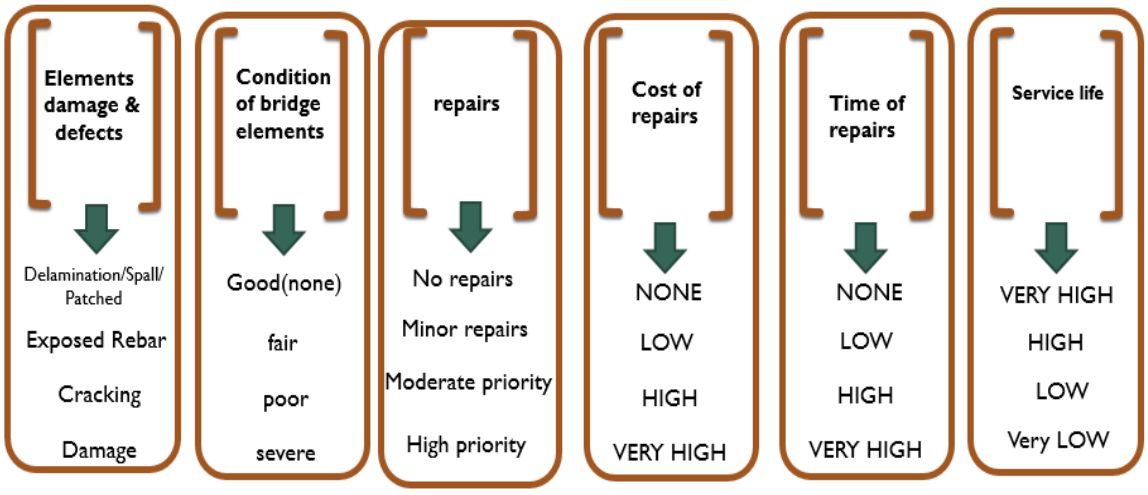
AND Strand Damage more than “25% from total number of strands”

AND the Cost of repair versus replacement “the cost of repair more than 70% of the replacement”

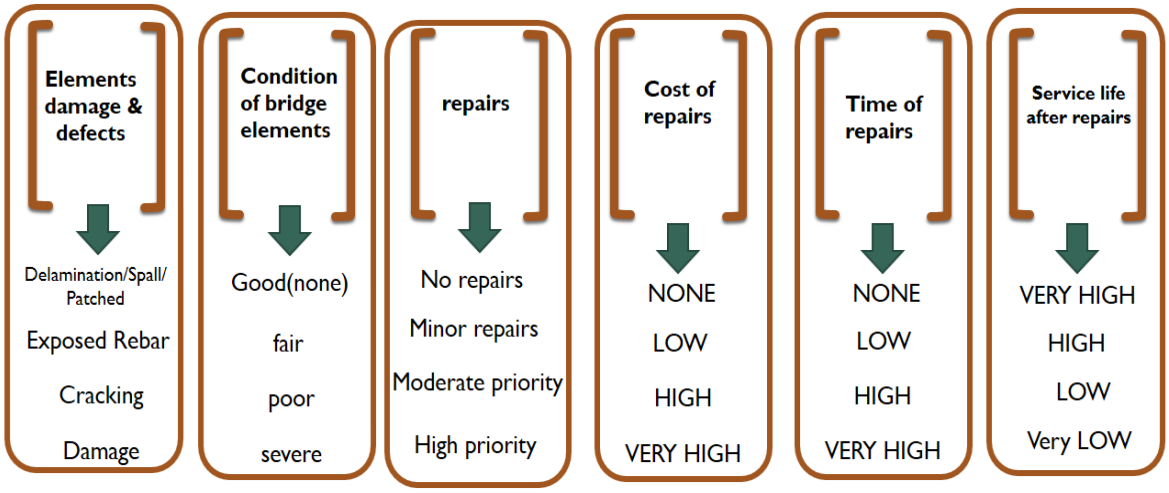
AND the Girder Displacements “The bottom flange is displaced horizontally position more than ½″ per 10′ of girder length.”

THEN select the repair of girder system “replacement girder”

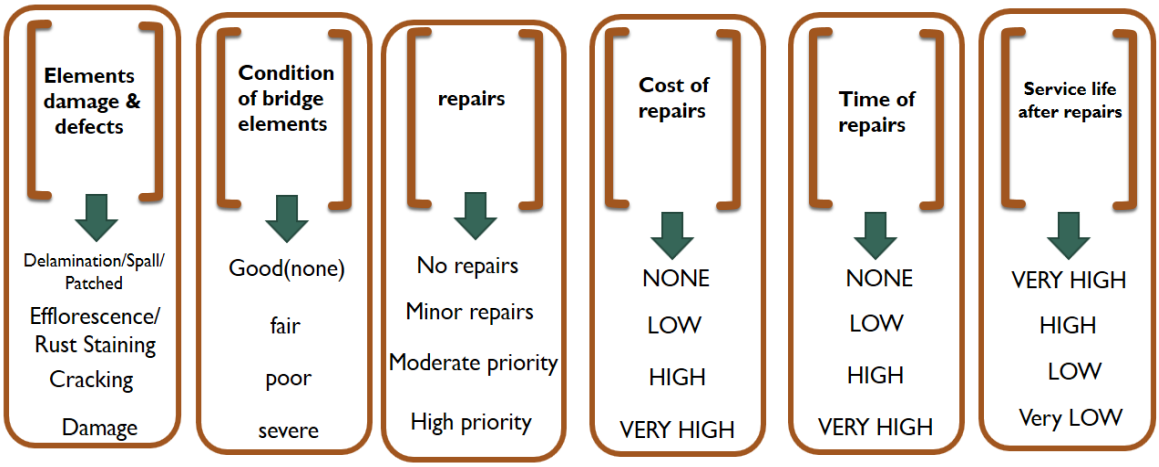
9.5 Flow Chart for (Deck/Slab)



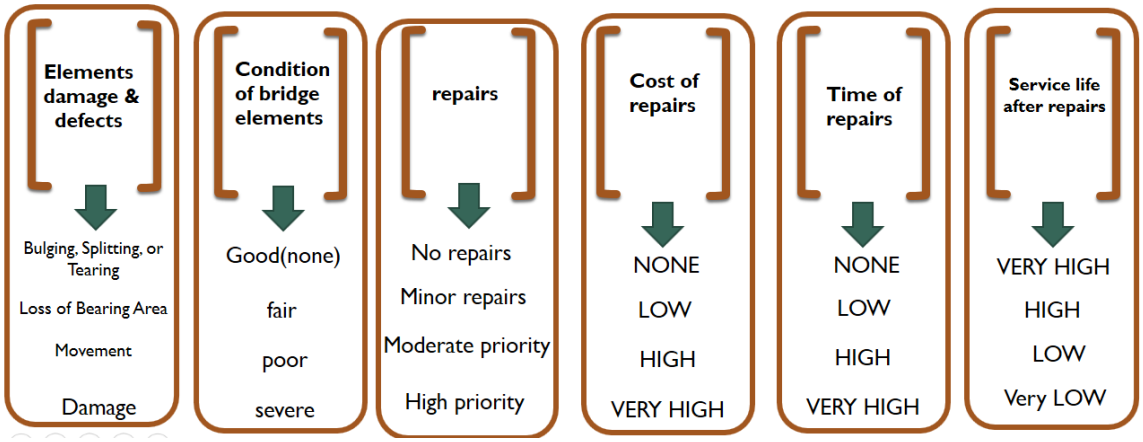
9.6 Flow Chart for (Superstructure)



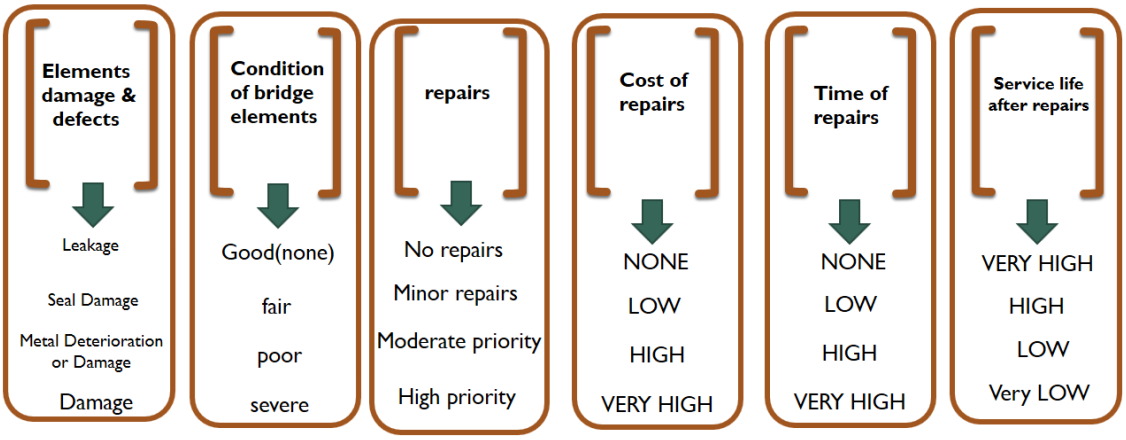
9.7 Flow Chart for (Substructures)



9.8 Flow Chart for (Bearing)



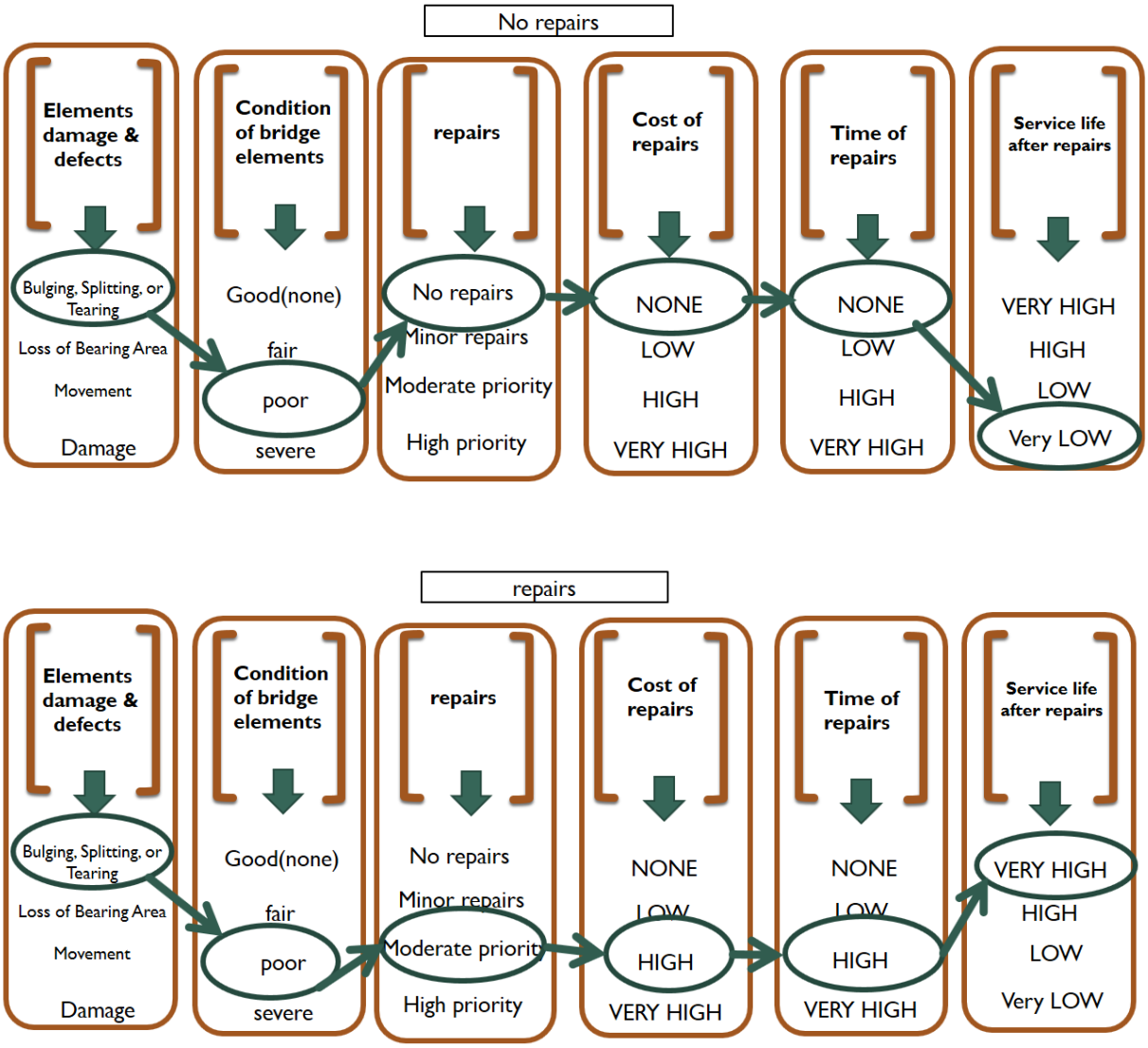
9.9 Flow Chart for (Joints)



9.10 Example (Condition State 3 Elastomeric Bearings)

Condition State 3
Significant cracking, splitting or bulging may be present. Moderate misalignment or lateral movement may be present. Dowels may be severely corroded.

9.11 Flow Chart for Example (Condition State 3 Elastomeric Bearings)



10. CASE STUDY USE PROTOTYPE EXPERT SYSTEM

Diamond Interchange Bridge (Prince MOHAMMED bin ABDULAZIZ) on Airport road in Taif city (see the location) Impact by truck carry bulldozer made big damage in the prestressed bulb-T girder (see the pictures).

As per visual investigation report the most concreter loss and the layout of cables prestressed move from position and the secondary reinforcement loss.[6]

Figure 10.1: Pictures for the damage in the girder

Figure 10.2: Location of bridge

10.1 Expert System Implementation

The engineer will use ***"Replacement girder"*** for this task as:-

Rule 1: **IF** The Damage of girder is "**RISK**"=yes

Then Go for (**RISK due to damages)**

Rule 2: **IF** (**RISK due to damages)** "danger for traffic" =yes

Then Close-traffic above the bridge

Rule 3: **IF** (**Condition of girder)** "severe" =yes

Then Go to (**Type of repairs)**

Rule 4 **IF** damages is severe use "External prestress" =yes

Then Check the "**Strand Damage less than "25% from total number of strands"**

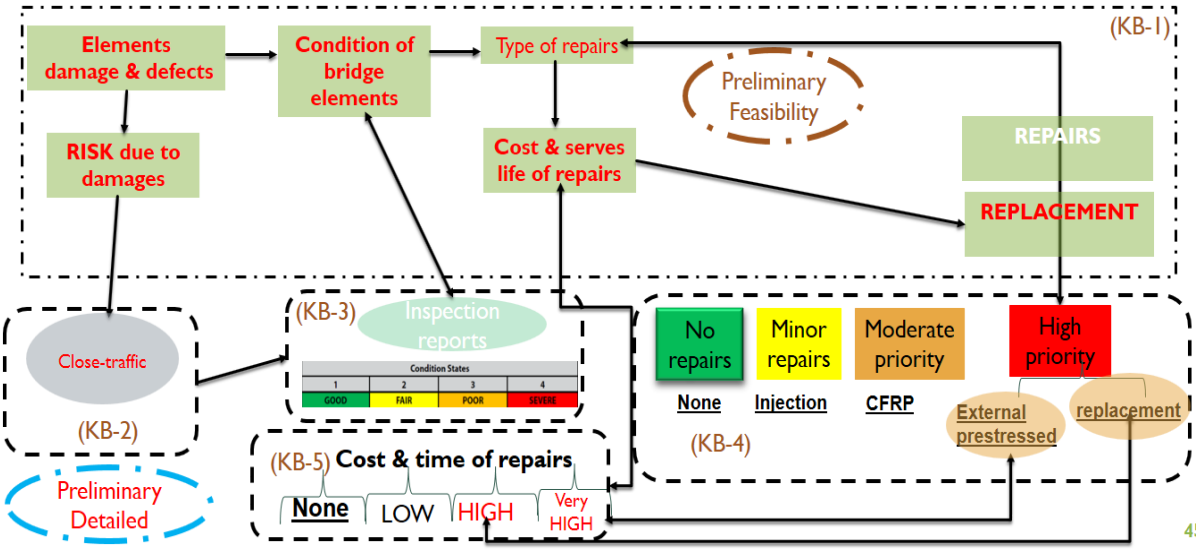
Rule 5 **IF** **Strand Damage less than "25% from total number of strands** = yes

Then Check the "**Cost of repair versus replacement**"

Rule 6 **IF** The cost of repair more than 70% of the replacement = "YES"

Then select **"REPLACEMENT GIRDER"** for Rehabilitation.

10.2 Expert System Implementation (Flow Chart)



10.3 Pictures of Replacement Girder

Figure 10.3: Support the damage of girder

Figure 10.4: construction & casting concrete girder

Figure 10.5: Replacement the girder

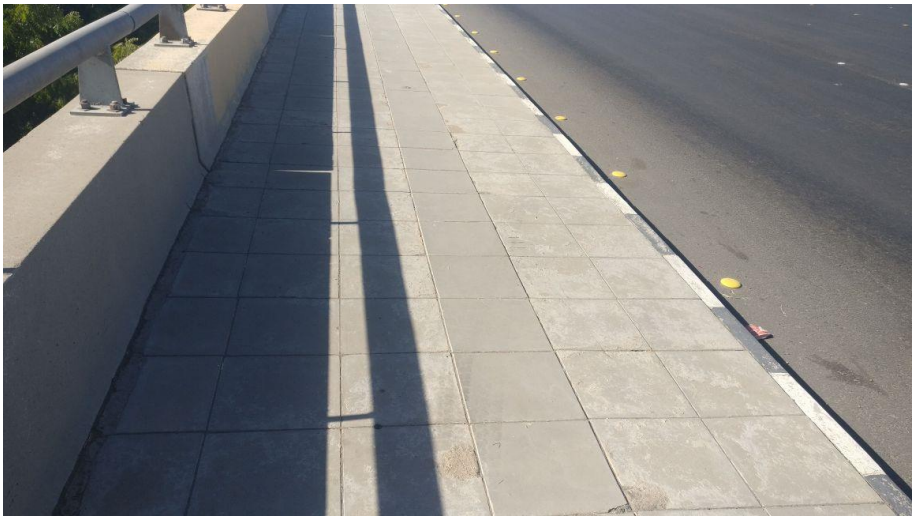


Figure 10.6: Bridge after repairs

11. CONCLUSION

- Selection of Bridge Rehabilitation methods depends on a lot of criteria such as Condition of bridge elements and type of Repair Methods the decision of selecting these criteria should be based on Inspection reports and cost of construction.
- Expert system created to assist the structural engineers to select the Bridge Rehabilitation methods.
- This expert system can be a useful Rehabilitation methods tool because of its convenience and the capability of providing an inexperienced engineer with default values for initial estimates of key variables.
- The program developed can easily combine new expert knowledge by simply adding several control statements and rules, without effecting on any existing part of the program.

12. REFERENCES

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