An Imaging System for Concrete Bridge Inspection

Mohammed Talal Al-Bataineh

Western Michigan University

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AN IMAGING SYSTEM FOR CONCRETE BRIDGE INSPECTION

by

Mohammed Talal Al-Bataineh

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Construction Engineering, Materials Engineering,
and Industrial Design

Western Michigan University
Kalamazoo, Michigan
December 2002
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2002
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Special thanks to Zhizhen Liu P.E. Bridge Engineer from the Michigan Department of Transportation (MDOT) for her help during the research.

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Finally, to my parents whom I gain the strength and the hope from, to my brothers Hassan and Abdullah, my sisters Basmh, Nour, and Rasha. And to my butterflies Rahma and Zain. Thanks for your love and support. All of you will live in my heart and mind forever.

Mohammed Talal Al-Bataineh
AN IMAGING SYSTEM FOR CONCRETE BRIDGE INSPECTION

Mohammed Talal Al-Bataineh

Western Michigan University, 2002

Bridges are the most important element in the road network because of the strategic position a bridge occupies, its direct impact on safety, and its high cost. Therefore, a continuous maintenance and inspection should be performed. During the past years visual inspection has been the primary method of bridge inspection.

Pontis is a comprehensive bridge management system developed as a tool to assist in the challenging task of bridge management. Pontis stores bridge inventory and inspection data and formulates network-wide preservation and improvement policies for use in evaluating the needs of each bridge in a network.

The concrete bridge inspection information system was created to replace the visual inspection using the imaging processing techniques. The redundant aspects were eliminated and the relational model was created using the Entity Relationship in the $3^{rd}$ normal form.

Both the Pontis elements and the condition rating were used as the link between the system and the Pontis.
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1.1 Background

Bridges are the most important element in the road network because of the strategic position they occupy, their direct impact on safety and their high cost. Therefore, continuous maintenance and inspection should be performed.

Today the road network in the United State of America consists of 3.8 million miles and 565 thousand bridges. Most of the bridges were built during the late 1800s and early 1900s because of the intensity of road construction during that time. More than 400 thousand bridges were built before 1935 (Dooley, 2001). Nowadays, almost 40% of the bridges are considered either structurally deficient or functionally obsolete. Preserving and improving our nation's bridge network is a complex and expensive, but vitally important task. What is needed is a careful and systematic allocation of funds and the formulation of an efficient maintenance and improvement policy that would derive the maximum benefit from the use of the limited funds available. M. J. Ryall stated (Ryall 2001):

"A BMS is more than collection of facts, it is a system that looks at all of the information concerning all of the bridges and is able to make comparisons between each in order to rank its importance within the overall infrastructure with regards to safety budgetary constraints. Basically it should be able to tell the bridge manager where he should be spending his funds in the most efficient way."

To achieve this goal a bridge management system was needed. A number of
systems were created to address bridge management need, in the United State of America. For example (Ryall, 2001):

- Pontis (Preservation, Optimization and NeTowrk Information System)
- BRIDGIT (BRIDGe Information Technology)
- PENBMS (PENnsylvania Bridge Management System)

This research project uses Pontis as a basis since it has become a national standard. The system developed in this research project will be integrated with Pontis using what is known as Pontis element (will be described later).

1.2 Project Objectives

The ultimate goal of this project is to fully automate the bridge inspection process. A completely automated inspection system will consist of an imaging data acquisition, data storage, and data interpretation models.

This thesis will focuses on developing an imaging information system data storage issues in support of the automated imaging inspection system for concrete bridges. The information system will be integrated with Pontis through the use of Pontis elements.

The objectives of the study are as follow:

- Review all the information related to bridge inspection.
- Study the inspection forms and extract all relevant data.
- Integrate the system with the Pontis using Pontis elements.
- Develop an imaging information model for bridge inspection using Entity-Relationship (E-R) modeling technique.
- Develop a relational database model from the E-R mode
- Develop a prototype imaging information system based on the relational
database mode

- Demonstrate the need of bridge inspection.

This proposed system will increase the safety of the inspectors by reducing or eliminating the number of field inspection trips and the required personnel. Also, it will reduce the human error by storing all the information, including the images, in the system, which we can be reviewed at any time.

1.3 Methodology

In this research an imaging inspection information system for concrete bridges, will be developed using the following four-step modeling methodology (see Figure 1.1):

- Data item analysis: The first step consists of an analysis of the inspection forms used by Michigan Department of Transportation, the data extracted from Pontis, and knowledge gained from of bridge literature review of the inspection.

- Conceptual data modeling: The Entity-Relationship (E-R) modeling information technique will be used to create the conceptual information model for the proposed system based on the data item analysis.

- Relational Modeling: The information model in step 2 will be transformed to a relational database schema. The relational schema will be in the $3^{rd}$ normal form.

- Computer Modeling: The last step will be the implementation of the system using a database management system software package.
1.4 Cracks in Concrete

Concrete can crack at any of the following stages (Raina, 1994): in its plastic-phase before setting, in its hardening-phase before applying the service load, and in its hardened-phase and in service after 28 days. Concrete can be cracked in the plastic-phase due to the following (Raina, 1994):

1- Plastic settlement
2- Plastic shrinkage
3- Differential settlement of supports

In the hardening-phase concrete can crack for different reasons such as:

1- Differential settlement of supports
2- Drying shrinkage
3- Thermal movement

In the hardening-phase and in service the crack may have occurred due to the following:
1- Under-design
2- Overload
3- Differential settlement of supports
4- Inadequate construction
5- Inadequate detailing
6- Sulphate attack on the cement in the concrete
7- Rusting of reinforcements due to
   a- Carbonation effect on concrete
   b- Chloride attack on reinforcement
   c- Simple oxidation of reinforcements due to exposure to moisture
8- Crazing
9- Weathering cracks
10- Alkali-aggregate reaction
11- Long term drying-shrinkage cracks

Various types of cracks will be discussed briefly below (Raina, 1994).

- **Plastic Shrinkage Crack.** This type of crack occurs within the first hour of placing the concrete. During that time the surface layer of the concrete will be exposed to evaporation that may cause shrinkage to occur in the thin layer. It is well-known that concrete in the plastic stage has no resistance to tensile forces. Plastic shrinkage cracks are most common in the slab element.
• **Splitting Crack.** This type of crack is caused by a highly concentrated force, for example in the anchorage zone for the prestressed cables and at bearing. There are primarily two types of splitting cracks. The first type, located very closed to the concentrated force, tries to split the concrete locally. Meshes of reinforcing bars can prevent the type cracks, the second type, caused by the trajectory distribution of the concentrated forces into the cross-section which normally will take place over a certain distance depending on the geometrical conditions.

• **Early Thermal Movement Crack.** The reaction between the cement and water is a chemical reaction produced by heat. If the concrete element is big and well isolated, then the rate of heat production will be bigger than the rate of heat loss during the first 24 hrs, and the concrete temperature will rise. After a few days, the rate of heat production will decrease below the rate of heat loss. This will make the concrete cool down causing the concrete element to contract. If there were no restraining boundaries, this contraction would not cause any crack. However, in practice, there is bound to be some restraint, either external or internal.

• **Support Settlement Crack.** This type of crack occurs mainly in indeterminate structures where there may be a significant differential settlement due to inadequate design of supports and foundation. These differential settlements will lead to flexural and shear forces in the structure which will causes additional stresses and lead to flexural and shear cracks.

• **Early and Long-term Drying-Shrinkage Crack.** This crack caused by volume changes due to moisture loss commonly termed as shrinkage. When the shrinkage process occurs in any part of the structure, a tensile stress develops. When these stresses exceed the concrete tensile stress capacity, cracks occur. In
massive concrete elements, tensile stresses are caused by the differential shrinkage between the surface and the interior concrete. Drying shrinkage may be defined as the reduction in volume of concrete caused by the chemical and physical loss of water during the hardening process and exposure to unsaturated air. Shrinkage occurs when the cement-water-gel loses water partly through evaporation and partly through cement hydration. The result is volume change, which may cause cracks only if the concrete restraint and the tensile stresses exceed the limit.

- **Overload Under-Design, Inadequate Construction, and Details Cracks.**
  Overload or under design will obviously create excessive stresses, consequently leading to corresponding cracking. Similarly, inadequate construction or inadequate detailing can lead to excessive stresses, possible cracking, even premature collapse.

- **Sulphate Attack Crack.** This type of crack results from corrosion of reinforcement, which is normally due to the oxidation under damp conditions resulting from inadequate concrete cover and porous concrete, or, more severely, the chloride attack on reinforcement under damp conditions, or from reduction in pH due to carbonation of concrete. Or alkali reacting with the reactive silicates and carbonates that may be present in certain aggregates cause these cracks essentially by the internal bursting pressures generated by the expansive nature of the chemical reaction (volume change action). Such cracks are consequently limited to situations where the surrounding atmosphere, water, soil and/or concrete constituents themselves can supply the pollutant, the concrete constituents can supply the reactant, and the porous or permeable nature of concrete-quality can allow the ingress through the vehicle of dampness.
• **Chloride Attack Crack.** In general, the reinforcement does not corrode when it is embedded in the concrete because a protective passive layer forms on its surface. But if the cover is insufficient or the concrete is permeable, then the passive layer will also break down in the presence of excessive amounts of chloride ions. The chlorides can originate from sodium chloride in marine locations or from de-icing applications. When the layer breaks the steel, it is susceptible to rust or corrosion. This is an expansive process, which can cause the concrete to crack and spall. To prevent this type of crack, one should ensure that the concrete is dense and increase the concrete cover.

• **Cracks Caused By Rusting of Reinforcement due to Carbonation.** Carbonation is a process in which carbon dioxide (in the atmosphere) reacts with dissolved calcium hydroxide in the pore water of the concrete structure, resulting in the formation of calcium carbonate. This reaction increases acidity as it reduces pH in the moisture of the concrete. Consequently, the reinforcing steel corrodes because the alkalinity of the concrete is reduced due to the reduction of pH value through carbonation, reducing the passivity around steel. The increased volume of the corrosion product causes radial bursting stresses around the reinforcing bar. This results in local radial cracks, which initiate spalling of the concrete. These cracks further provide easy access for oxygen, moisture, and chlorides in the concrete, creating a condition whereby corrosion continues and causes further cracking, and, finally, significant spalling.

• **Cracks Caused By Rusting of Reinforcement due to Moisture Exposure.** Reinforcement, prestressing steel, and most of the steel elements, if left exposed to moist atmosphere, will rust due to the chemical reaction of oxidation. This reaction will continue even if such steel is embedded in concrete. Since rust
occupies much more volume than the basic metal, the process creates radial expansive pressure on the surrounding concrete and bursts it, forming an initial crack line. This can lead to further separation of sheets of concrete and eventually the damage associated with rust distress.

- **Alkali-Aggregate Reactive Crack.** A rare form of expansion and cracking can occur under damp conditions following the reaction of some forms of silica and carbonates in certain aggregates with the alkalis in cement. The reaction between the silica and the alkali produces a gel, which occupies more volume and, hence, causes expansion and cracks, usually moving away from the source of expansion. However, these cracks may join others and form a map pattern similar to crazing. Alkali-aggregate reaction, like chloride and sulphate attacks, can take place only under wet or damp conditions. Positive identification can be made only by means of laboratory tests on samples of concrete removed from the structure.

- **Fabrication, Shipment and Handling Cracks.** A major cause for cracks in precast concrete members can result from errors in fabrication, combined with stresses induced during shipment and handling. These cracks may occur in variable shapes, sizes, and locations of the member.

### 1.5 Pontis

Pontis is a comprehensive bridge management system developed as a tool to assist in the challenging task of bridge management. Pontis stores bridge inventory and inspection data, formulates network-wide preservation and improvement policies for use in evaluating the needs of each bridge in a network, and makes recommendations regarding which projects to include in an agency's capital plan for deriving the maximum benefit from limited funds. Developed in 1989 for the Federal
Highway Administration (FHWA), Pontis is currently licensed through the American Association of State Highway and Transportation Officials (AASHTO) to over forty state Departments of Transportation and other agencies.

1.5.1 Pontis Objectives

Pontis supports the entire bridge management cycle, allowing user input at every stage of the process. The system stores bridge inventories and records inspection data. Once inspection data have been entered, Pontis can be used for maintenance tracking and federal reporting. Pontis integrates the objectives of public safety and risk reduction, user convenience, and preservation of investment to produce budgetary, maintenance, and program policies. Additionally, it provides a systematic procedure for the allocation of resources to the preservation and improvement of bridges in a network. Pontis accomplishes this by considering both the costs and benefits of maintenance policies versus investments in improvements or replacements.

1.5.2 Pontis Element

Because the system described in this thesis focuses on concrete bridges, the elements used in system will be concrete. Based on Pontis, the elements can be divided into four major categories:

1- Deck/Slab
2- Superstructure
3- Substructure & Culvert
4- Miscellaneous

The following subsections provide a brief overview of the different elements
1.5.2.1 Deck/Slab

There are 16 different elements in this category as shown in Table 1.1 shows them.

Table 1.1 Deck/Slab Elements (Pontis 1998)

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Element Description</th>
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<tbody>
<tr>
<td>012</td>
<td>Bare Concrete Deck</td>
</tr>
<tr>
<td>013</td>
<td>Unprotected w/AC Overlay Concrete Deck</td>
</tr>
<tr>
<td>014</td>
<td>Protected w/AC Overlay Concrete Deck</td>
</tr>
<tr>
<td>018</td>
<td>Protected w/Thin Overlay Concrete Deck</td>
</tr>
<tr>
<td>022</td>
<td>Protected w/Rigid Overlay Concrete Deck</td>
</tr>
<tr>
<td>023</td>
<td>Bare Protected w/Coated Bars Concrete Deck</td>
</tr>
<tr>
<td>027</td>
<td>Protected w/Cathodic Protection Concrete Deck</td>
</tr>
<tr>
<td>038</td>
<td>Bare Concrete Slab</td>
</tr>
<tr>
<td>039</td>
<td>Unprotected w/AC Overlay Concrete Slab</td>
</tr>
<tr>
<td>040</td>
<td>Protected w/AC Overlay Concrete Slab</td>
</tr>
<tr>
<td>044</td>
<td>Protected w/Thin Overlay Concrete Slab</td>
</tr>
<tr>
<td>048</td>
<td>Protected w/Rigid Overlay Concrete Slab</td>
</tr>
<tr>
<td>052</td>
<td>Protected w/Coated Bars Concrete Slab</td>
</tr>
<tr>
<td>053</td>
<td>Protected w/Cathodic Protection Concrete Slab</td>
</tr>
<tr>
<td>035</td>
<td>Bare Precast Panel Concrete Deck</td>
</tr>
<tr>
<td>036</td>
<td>Protected w/AC Overlay Precast Panel Concrete Deck</td>
</tr>
</tbody>
</table>
1.5.2.2 Superstructure

In this category there are 10 elements as shown in the Table 1.2

Table 1.2 Superstructure Elements (Pontis 1998)

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>104</td>
<td>P/S Concrete Closed Web/ Box Girder</td>
</tr>
<tr>
<td>105</td>
<td>Concrete Closed Web/ Box Girder</td>
</tr>
<tr>
<td>109</td>
<td>P/S Concrete Open Girder</td>
</tr>
<tr>
<td>110</td>
<td>Concrete Open Girder</td>
</tr>
<tr>
<td>115</td>
<td>P/S Concrete Stringer</td>
</tr>
<tr>
<td>116</td>
<td>Concrete Stringer</td>
</tr>
<tr>
<td>143</td>
<td>P/S Concrete Arch</td>
</tr>
<tr>
<td>144</td>
<td>Concrete Arch</td>
</tr>
<tr>
<td>154</td>
<td>P/S Concrete Floor Beam</td>
</tr>
<tr>
<td>155</td>
<td>Concrete Floor Beam</td>
</tr>
</tbody>
</table>

1.5.2.3 Substructure & Culverts

This category includes four elements used as foundation elements in a bridge, see Table 1.3.
1.5.2.4 Miscellaneous

There are four elements in this category; see Table 1.4

Table 1.4 Miscellaneous Elements (Pontis 1998)

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>321</td>
<td>P/S Concrete Approach Slab</td>
</tr>
<tr>
<td>331</td>
<td>Concrete Bridge Railing</td>
</tr>
<tr>
<td>340</td>
<td>Superstructure Concrete Coating</td>
</tr>
<tr>
<td>341</td>
<td>Substructure Concrete Coating</td>
</tr>
</tbody>
</table>

1.5.3 Pontis Rating

During visual inspection, the Inspector gives each element a rating for its condition. These ratings are used to describe the existing in-place bridge as compared to the as-built condition.

Table 1.5 provides the general ratings used in Pontis to describe element condition.
<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Not applicable.</td>
</tr>
<tr>
<td>1</td>
<td>Excellent condition.</td>
</tr>
<tr>
<td>2</td>
<td>Very good condition - no problems noted.</td>
</tr>
<tr>
<td>3</td>
<td>Good condition - some minor problems.</td>
</tr>
<tr>
<td>4</td>
<td>Satisfactory condition - structural elements show some minor deterioration</td>
</tr>
<tr>
<td>5</td>
<td>Fair condition - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.</td>
</tr>
<tr>
<td>6</td>
<td>Poor condition - advanced section loss, deterioration, spalling or scour.</td>
</tr>
<tr>
<td>7</td>
<td>Serious condition - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.</td>
</tr>
<tr>
<td>8</td>
<td>Critical condition - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.</td>
</tr>
<tr>
<td>9</td>
<td>&quot;Imminent&quot; failure condition - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.</td>
</tr>
<tr>
<td>0</td>
<td>Failed condition - out of service-beyond corrective action.</td>
</tr>
</tbody>
</table>
1.6 Entity Relationship Modeling

The key idea of the Entity-Relationship (E-R) approach is to add an intermediate stage in information system design. The system designer first identifies the entities and relationships, which are of interest to the enterprise using the E-R diagrammatic techniques. At this time the designer should view the data from the point view of the whole enterprise. Enterprise view is called the enterprise schema.

The E-R approach to information system design consist of two major phases (Chen 1977): (a) defining the enterprise schema using the entity-relationship diagram, and (b) translating the enterprise schema into a user schema.

The following are the notations used in the Entity Relationship diagram (see Figure 1.2):

![Entity Relationship Diagram Notation](image)

Figure 1.2 Entity Relationship Diagram Notation
As an example, consider Figure 1.3. In this figure both “Element” and “Image” represent an entity, and “has” represents the relationship. The “Element ID” and “Element Description” represent attributes for the Element entity. The relationship between the two entities is one-to-many which means that each element has many images but each image describes one element.

Figure 1.3 An Example of the Entity-Relationship Notation
CHAPTER II

INSPECTION

The first formal requirement for the inspection of highway bridges was established in 1967 because of the collapse of the Silver Bridge in Point Pleasant, West Virginia. Now, after more than thirty years, visual inspection remains the key method of bridge inspection. However, new techniques for a non-destructive evaluation (NED) of highway bridges have emerged in recent years (OECD, 1976 & Washer, 1998). It is known that bridges are the key elements of the road system. The primary aim of bridge inspection is safety of the structure. The public does not accept the minimum risk of failure, although this may be impossible to achieve, technically or economically. Therefore, it has become a political decision to have a balance between the requirement to maintain public confidence and available resources for ensuring an appropriate level of safety. Another reason for bridge inspection is to protect the capital invested in the inventory of bridges with minimal operational cost. Timely and economical planning and programming of remedial and preventative maintenance and repair work, or even bridge replacement, with the minimum impact traffic, depends on systematic and detailed bridge inspection and on expert assessment of data. Fortunately, it is rare to have failures of bridges in service, especially those leading to personal injury. More common is accidental damage arising from impact by vehicles or vessels.
The 1967 Point Pleasant Bridge collapse in West Virginia was the most catastrophic bridge accident. The collapse of that bridge caused the death of forty-six people. The collapse was caused by a very small stress corrosion crack located on the inner portion of an eyebar, high above the roadway in the suspension chain. The crack precipitated a brittle fracture of the bar, causing joint instability and subsequent collapse of the structure (OECD, 1976). This accident highlights the need to design and construct bridges that are accessible and inspectable and to advance inspection technology in general to make it possible to detect such small cracks.

There were also several bridge failures that did not lead to any human losses. In some cases ‘last minute’ inspection permitted taking the necessary emergency measures, such as bridge closures. However, systematic and timely inspection in these cases could certainly extend the service life of the bridge and would not cause any hazardous situations to the public. To assess bridge safety, one should take on account several individual factors, which may be grouped together as follows (OECD, 1976):

1. Human (degree of acceptable or reasonable safety risk).
2. Technical (design, materials, construction, maintenance)
3. Regulatory and Enforcement (traffic, authorized bridge loading)
4. Environmental (climatic)
5. Economic (the notion of service life, optimizing total life cost)
6. Political.

Common sense tells us that the bridge will be subjected to increases in vehicle load at times. The aim of inspection is to identify and quantify deteriorations which
may be caused by applying the loads (dead load, vehicular load, wind, physical and chemical influences exerted by the environment, etc.). Apart from inspection of bridge damage caused by unpredictable natural phenomena or collision by vehicles or vessels, inspection is also needed to identify the effects of any built-in imperfections.

It is necessary to keep close and systematic watch on the bridge structure, in order to ensure that appropriate economic action is taken in time. It's clear that if traffic has to be interrupted on a bridge as a result of the occurrence of a serious damage without having a plan to repair and reconstruct, the cost to the community will be very high. There has been rapid technological development in both bridge design and construction such as welding techniques, high strength bolts, erection techniques, segmental construction, and development in appurtenances. During the sixties there was also an unprecedented increase in road and bridge building. In view of these rapid developments, it is only natural that a number of design and construction imperfections have occurred, the effects of which will appear only in the long term.

Bridge inspection allows for the economical planning and programming of maintenance, repair, and reconstruction work and may extend the scheduling of national replacement programs over a longer period of time due to timely maintenance. (OECD, 1976)

2.1 Types Of Inspection

There are many types of bridge inspection, five of which will be discussed in the following subsections (AASHTO, 1994). Such items as the extent of access to structural elements, the level of detail required for physical inspection, and the degree of testing will vary considerably for each type of inspection.
2.1.1 Initial Inspection

This is the first inspection type of bridge, as it becomes part of the bridge file. Also, it may be applied when changes are made to the structural configuration of the bridge such as widening, lengthening, and supplemental bents, or it may come about when there is a change in the ownership of the bridge.

This type of inspection involves a fully documented investigation performed by persons meeting the required qualifications for inspection, and it must be accompanied by an analytical determination of load capacity.

The purposes of the initial inspection are as follows:

1. It should provide all the structural inventory and appraisal data required by federal and state regulation and all the relevant information collected by the owner.

2. It should determine the baseline of the structural conditions and identify and list any existing problems or those involving the location of the structure that may lead to potential problem.

During this inspection any fracture of critical members or details is noted and assessments are made of other conditions that may later warrant special attention.

2.1.2 Routine Inspection

This type of inspection is used to identify any changes from the initial or previously recorded conditions and to insure that the structure still satisfies present service requirements. The routine inspection must fully satisfy the requirements of the national bridge inspection standards with respect to the maximum inspection frequency, the updating of structure inventory and appraisal data and the qualifications of the inspection personnel. (AASHTO, 1994)

These inspections are conducted on the deck, ground, or water level, and
permanent work platform and walkways. An under water inspection portion of the substructure is limited to observations during low-flow periods and/or probing of undermining. The most important areas to be closely monitored by Routine Inspection are those previously determined to be critical to load capacity.

At the end of the Routine Inspection, the results should be documented with selected photos, and the written report should include any recommendations for maintenance or repair and for future scheduling of In-Depth Inspections, if necessary. Also, the load capacity should be re-calculated to observe any changes.

2.1.3 Damage Inspection

This is an unscheduled inspection to assess structural damage resulting from environmental factors or human action. The main reasons for this inspection are to determine the need for emergency load restrictions or to close the bridge to traffic and to assess the level of effort necessary to effect a repair. The amount of effort expected from this type of inspection may vary significantly depending upon the extent of the damage. If major damage has occurred, inspectors must evaluate fractured members, determine the extent of section loss, make measurements for misalignment of members, and check any loss of foundation support. (AASHTO, 1994)

A capability to make on-site calculations to establish emergency load restrictions may be desirable. This inspection may be followed by an In-Depth Inspection to document more fully the extent of the damage and the urgency and magnitude of repairs. Proper documentation, verification of filed measurements and calculations, and more refined analysis to establish or adjust interim load restrictions are required follow-up procedures.
2.1.4 In-Depth Inspections

An In-Depth Inspection can be defined as a close-up, hands-on inspection for one or more elements above or below the water level to identify any deficiencies not detectable using Routine Inspection procedures. Special equipment, such as underwater inspection equipment, staging and workboats should be provided to obtain access, if needed. Personnel with special skills may be needed. Non-destructive testing procedures may be used to identify the existence or the extent of any deficiencies.

In-Depth Inspection may include a load rating assessment of the residual capacity of the member or members, depending on the deterioration or damage existence. A non-destructive load test may be used to determine the bridge load carrying capacity. This type of inspection could be scheduled independently of a Routine Inspection, generally at a longer interval of time, or after a Damage Inspection or Initial Inspection.

For small bridges it should include all critical elements of the structure. For larger and more complex structures, it may be scheduled separately for defined segments of the bridge or for designated groups of elements, connections or details that can be efficiently addressed by the same or similar inspection techniques. Each designated group or defined bridge segment should be recorded and assigned a frequency schedule for re-inspection. As in Initial and Routine Inspections, all activities, procedures, and results should be completely documented.

2.1.5 Special Inspections

This is an inspection scheduled by the owner of the bridge. It is used to monitor a particular or suspected deficiency such as member condition, foundation
settlement, or the public's use of a load-posted bridge. Any qualified person familiar
with the bridge and available to accommodate the assigned frequency of investigation
can perform it. They should be carefully instructed regarding the nature of the known
deficiency and its functional relationship to satisfactory bridge performance. Special
inspections usually are not sufficiently comprehensive to meet NBIS requirements for
biennial inspections.

2.2 What to Inspect

All bridge elements should be inspected. The bridge elements can be
categorized as follows: Substructures, Superstructures, Decks, Approaches, Signs,
Waterways, Box Culverts as Bridges, Corrugated Metal Plate Structures, and
Encroachments. (AASHTO, 1994)

2.2.1 Substructures

The substructure inspection involves the examination and recording of any
signs of damage, deterioration, movement and, if in water, evidence of scour. The
following elements of the substructure should be inspected:

1. Abutments.
2. Retaining walls.
3. Piers and Bents.
4. Pile Bents
5. Bridge Stability and Movement.
6. Dolphins and Fenders.
2.2.2 Superstructures

In general, the superstructure elements are composed of reinforced concrete, structural steel, or timber, including bearings, connection devices, and protective coating. Girders over a traveled way should be checked for any damage resulting from being struck by overnight loads passing under the bridge. If feasible, the inspector should note any excessive vibration or deflection as truck loads move across the superstructure.

Where the deck obscures the steel flange or if the steel member is totally encased, the inspector may recommend that portions of the covering material be removed at random locations to determine if significant section loss has occurred.

The superstructure may consists of the following elements (AASHTO, 1994):

1. Steel Beams, Girders and Box Sections.
2. Reinforced Concrete Beams and Girders.
3. Prestressed Concrete, Beams, Girders and Box sections
4. Timber system.
5. Floor Systems.
6. Trusses.
7. Cables.
8. Diaphragms and Cross-Frame.
10. Rivets, Bolts, and Welded Connections.
11. Pins and Hangers.
13. Paints
14. Utilities
15. Arches.

2.2.3 Decks

Decks are primarily composed of reinforced concrete, prestressed concrete, steel, and timber. Decks should be inspected separately from the superstructure. Also, decks include expansion joints, railings, sidewalks and curbs, bridge drainage, and lighting which is attached to the bridge.

Generally, decks are designed to support the live load integrated with the supported elements of the superstructure. The inspector should insure that these work properly. The following are the basic elements of decks (AASHTO, 1994):

1. Concrete Decks.
2. Prestressed Concrete Decks Panels.
3. Steel Decks.
4. Timber Decks.
5. Expansion Joints.
6. Railings, Sidewalks, and Curbs.
7. Bridge Drainage.
8. Lightning.

The inspector should assess the condition of the deck overlay. The condition of the overlay at the curb lines, joints, and scuppers should be reported. The extent of surface deterioration should also be reported as well as the overlay thickness.

2.2.4 Approaches

All features of the approaches should be inspected. For example:

1. The approach pavement should be checked for cracking, unevenness, settlement, or
roughness.

2. The approach roadway drainage should be directed away from the bridge.

3. The inspector should be familiar with all traffic safety features such as steel rail or wire cable approach guide rail, slope-faced concrete barriers, and impacted attention devices.

4. The inspector should check approach slope embankment for evidence of excessive erosion, settlement, undermining of pavement, curbing, or guide railing.

2.2.5 Signs

The inspector should be familiar with all kinds of signs used to show restricted weight limit, reduced speed limit, impaired vertical clearance or closure and their proper placement. The inspector should check the signs to see that the lettering is clear and legible and that they are in good condition. The bridge owner should designate the parties responsible for replacing missing or damaged signs and removal of vegetation and otherwise restoring sign visibility. The inspector should know to whom sign deficiencies are to be reported.

2.2.6 Waterways

The adequacy of the waterway opening under the structure should be assessed. The inspector should bear in mind the potential for debris build-up during periods of high flow and the hazard posed by ice jamming under the bridge during winter and early springtime. (AASHTO, 1994)

A channel profile record for the structure should be developed and revised as significant changes occur. This provides an invaluable record of the tendency toward scour, channel shafting, or degradation. A study of these characteristics can help
predict when protection of pier and abutment footings may be required to avoid or minimize future problems. Areas upstream and downstream of the bridge should be checked to see if the bridge and its approaches are causing any problems or potential problems.

2.2.7 Box Culverts as Bridges

According to the AASHTO, the single or multi cell reinforced box culverts are classified as bridges. The inspector should check for outward evidence of settlement or other movement by observing any sag in the profile of the roadway overhead, sag of the culvert floor or in the underside of the top slab, differential movement at joints in the box, and rotation of the wing walls at the ends of the box.

Also, the inspector should check the sidewalls, base slab, and any footings for abrasion, cracking or other deterioration of the concrete surface.

2.2.8 Corrugated Metal Plate Structures (CMP)

These depend on the interaction with backfill soil for their stability and ability to carry loads. The CMP arch is a compression ring with little bending resistance. The shape of the CMP arch should be inspected and compared to the as-built shape. Any flattening of the top arch elements or sides should be highlighted, and all changes from the as-built condition or previous inspections should be noted. The backfill material at the outlet should be inspected for evidence of material being removed from underneath and alongside the structure due to water infiltration. The base of the CMP arch should be checked for differential settlement or undermining.
2.2.9 Encroachments

Signs and sign structure, utilities, dense vegetation, and debris are all examples of encroachments. Theses may be man-made or natural elements that restrict the clearance under or above the bridge.

The inspector should note if an encroachment is located where there is a possibility that it may be hit and damaged by traffic. The horizontal and vertical clearances should be checked by field measurements particularly after repaving projects.

2.3 Methods of Inspection

Methods of inspection are the techniques used to evaluate various elements of the bridge. Those methods can be destructive and non-destructive. In this section I will focus on the non-destructive methods. Four methods of inspection will be discussed in the following subsections.

2.3.1 Visual Inspection:

Visual inspection is the primary method for evaluation in service highway bridges. During a typical bridge inspection, the various components of a structure are examined at close range by trained inspectors who evaluate the condition of the components and give it a rank. This rank is based on the subjective evaluation of the current condition by the inspector who in turn bases his rank on the guideline and on his experience. (Washer 1998)

For many situations, this type of evaluation is appropriate and effective. However, due to the subjective nature of this evaluation, ranks of similar bridge component conditions can vary widely from one inspector to another, and from one
state to another.

In many circumstances, this method of inspection not is appropriate. From some component geometries, such as pin and hanger connections, the area of interest is hidden from view. In other cases, such as concrete bridge decks, the surface condition may not be indicative of the internal condition of the component. Internal defects, typically delimitations occurring due to corroding steel, cannot be detected visually. The same is true for many other defects that may occur in highway bridges.

Possibly the most important thing visual inspection provides is the ability to provide objective and quantitative information on the condition of a bridge component. Visual inspection these days is based on an arbitrary rating system and the inspector’s notes to determine the condition of various bridge components. It is hard to determine the structural capacity rating, appropriate maintenance action, and remaining life of the structure.

In general, visual inspection has the following advantages and disadvantages:

1. Excellent assessment and interpolation of the inspected subject based on knowledge and experience.
2. Excellent capability and analyze complex scenes encountered during inspection tests.

The disadvantages of visual inspection include:

1. Subjective inspection results.
2. High inspection cost and low inspection speed.
3. Inspection errors due to: fatigue, environmental conditions, and repetitive nature of the inspection process,
4. Liabilities due to hazardous environment.

It is important to note that visual inspection is a qualitative method. Other
methods are quantitative (Shubinsky, October 1994).

2.3.2 Impact Echo Method

The Impact Echo method involves non-destructive testing of concrete based on the use of impact-generated waves that propagate through the concrete and are reflected by internal flows and external surfaces. It can be used to determine the location and extent of flows such as cracks, delaminations, voids, honeycombing, and debonding. The method can also be used to locate voids in the grouted tendon ducts in many post-tensioned structures.

This method has achieved success in locating flows and defects in highway pavements, bridges, buildings, tunnels, dams, piers, sea walls, and others. Its use saved millions of dollars in bridge repairs and retrofit costs.

It is used most successfully to identify and quantify suspected problems within the structure, in quality control applications such as measuring the thickness of new highway pavements, and in preventive maintenance programs such as routine evaluation of bridges decks to detect delaminations.

Impact Echo is based on the use of transient stress waves generated by elastic impact. A diagram of the method is shown in Figure 3.1. A short duration mechanical impact, produced by tapping a small steel sphere against a concrete or masonry surface, is used to generate low-frequency stress waves that propagate into the structure and are reflected by flows or external surfaces. Surface displacements caused by reflections of these waves are recorded by a transducer located adjacent to the impact. The resulting displacement versus time signal is transformed into frequency domain, and plots of amplitude versus frequency are obtained. Multiple reflections of stress waves between the impact surface, flows, and/or other external
surfaces give rise to transit resonance which can be identified in the spectrum and used to evaluate the integrity of the structure or to determine the location of flows. It can determine the thickness of the concrete with better than three percent accuracy, and can locate the void in the sub-grade directly beneath slabs and pavements.

The Impact Echo test was first developed for the case of the flat slab. In a sound slab, there is one thickness resonant echo peak that corresponds to the echo of the compression stress wave energy back and forth between the top and bottom of a slab.

2.3.3 Infrared Imaging

This is a non-destructive optical method for bridge inspection, in which a two-dimensional mapping of steady or transit thermal effects are constructed from the measurement of infrared energy emitted by the target. The recent development of high density imaging sensors has led to a new level of application unreachable prior to this technology. An active or transit technology was selected as a new method for bridge inspection. This method is dissimilar to the conventional thermographic methods in the utilization of time-dependent heating/cooling of the target. An external heating or cooling is applied in the form of short pulses, depending on the type of defect and the thermal characteristics of the target. Then a differential time-resolved infrared image analysis is performed following the created thermal perturbation.

Infrared imaging can be used to determine the coating defect or excessive corrosion of the steel bars based on the differences in the thermal diffusivity between the defective and non-defective areas.
The infrared imaging works by following propagation and detection of an induced thermal perturbation. The induced thermal can be imagined to flow from the exposed surface into the material. For a defect-free, homogenous material, the wave front of heat passes through uniformly. Alternatively, when there are cracks, they create higher thermal impedance to passage of the wave front.

When the defects are close to the surface, they restrict the cooling rate due to an insulation blocking effect and thereby produce hot spots. When a thermal imager views this surface, temperature differences arising from the defect’s presence become clearly visible shortly after the deposition of the heat pulse.

On the opposite side, because the defect impedes the passage of heat which warms this surface, the defect appears as a cold spot against the background heat that arrives. Infrared imaging has already been used to detect loose bolts in bolted
connection plates as well as delaminations in the bridge coating system.

Infrared imaging technology has now reached the point where there are a number of commercially available systems that can be fitted to a bridge inspection application. Inspectors used have thermographers on a variety of bridges to roughly evaluate the thermograph’s potential and have seen many interesting differences that lead us to believe that there are a wealth of bridge condition data available to the latest generation of Infrared Imaging thermographers. (Shubinsky, June 1994)

The following are reasons that Infrared Imaging did not spread widely in bridge inspection:

- Cost and Complexity of Equipment
- Infrared sensor limitations
  1. Minimal resolvable temperature differences
  2. Limited selection of operating wave lengths
  3. Low spatial resolution
  4. Inadequate long-term stability and responsibility
  5. Laboratory-type packaging inadequate for bridge inspection.
- Lack of real-time image and data processing hardware and software.
- Lack of understanding of thermographic testing specific to bridge defects
- Complexity of required data reduction.
CHAPTER III

IMAGING TECHNIQUES

This chapter will provide a brief overview of some of the imaging techniques and systems used in bridge and pavement condition assessment. The first section is edge-detection techniques, and the second section is using imaging processing techniques for pavement distress surveys.

3.1 Edge-Detection Techniques

Several imaging techniques can be used for the identification of cracks in image. These techniques are known as Edge-Detection techniques. An edge can be defined as a significant local change in the image. It is an important feature for analyzing the image, usually associated with a discontinuity in either the image intensity or the first derivative of image intensity. There are two types of image discontinuity (Jain, 95):

1- Step discontinuity where the image intensity suddenly changes from one value on one side of the discontinuity to another value on the opposite side.

2- Line discontinuity where the image intensity suddenly changes value but then returns to the same value after a short distance.

Edge detection is frequently the first step in recovering information from an image. There are a number of edge detection techniques such as

1- Gaussian Edge Detection

2- Canny Edge Detection

3- Sobel Edge Detection
The following are four techniques that were used in a parallel research at Western Michigan University during summer 2002 to isolate the cracks from the image (Kelly, 2002).

- **Fast Haar Transform**: The Haar transform, almost 100 years old, is the simplest example of an orthonormal wavelet transform. It decomposes an image into horizontal, vertical and diagonal edges at different (binary) scales.

- **Fast Fourier Transform**: The Fast Fourier Transform is a frequency-based transform developed by Tukey and Cooley in 1965 (Cooley, 1965). It is an extremely popular transform in the engineering world with a wide range of applications.

- **Sobel Edge Detector**: Sobel is a simple and fast technique to find the vertical and horizontal edges of an image.

- **Canny Edge Detector**: Canny is the first derivative of a Gaussian and closely approximates the operator that optimizes the product of single-to-noise ratio and localization. It is a convolution filter, and is slightly more complicated and powerful than the Sobel. Canny uses several convolutions to first blur the image and then attempt to detect edges. This succeeds in eliminating a great deal of noise and thus makes it a very effective technique.

The bridge images used in this thesis were created from the these edge-detection techniques used by Kelly, 2002.
3.2 Using Image Processing Techniques for Pavement Distress Surveys

Image processing has been widely used recently in automating the manual collection and visual rating of pavement surface conditions. The use of the automatic imaging system to capture and extract pavement and bridge-surface distress would improve safety and efficiency and offer consistency and uniformity of data and data quality. A number of pavement distress surveys systems will be discussed in the following pages. (Stephen 1990)

3.2.1 PASCO ROADRECON System

The PASCO Corporation of Japan developed the continuous pavement surface-photographing device (ROADRECON-70) in the late 1960s (Benson, 1988). The first operational survey vehicle was produced in 1970. Cracking, patching, and other distresses are recorded using the ROADRECON-70. The vehicle travels at speeds between 3 and 53 mph. A continuous photographic record of the pavement surface is made using a 35-mm slit camera. The system synchronizes film feed speed and camera aperture with the speed of the vehicle in order to equalize image density and photographic reduction. Road width of up to sixteen feet can be filmed.

A technician viewing the developed 35mm film enlarged ten times on the ROADRECON film digitizer makes interpretations of the distresses. A grid pattern is overlaid on the film to aid in quantification of the distress for input into a computer database.

3.2.2 GERPHO System

The Group Examine Router Photographic (GERPHO) system developed in France by the minister of transportation employs a survey vehicle to take continuous
35-mm photographs of the pavement surface. The GERPHO has been used extensively in France since 1972. It has also been used to a limited extent in several other countries. The system is similar to ROADRECON-70 (Benson, 1988).

The GERPHO system consists of a 35mm continuously running camera, mounted on a van, with a light source that illuminates the pavement. The pavement surveys are conducted at night to allow for uniform lighting conditions. The camera is fitted with a 14.5mm lens with an aperture of F-3.5. The picture covers a width of pavement of fifteen feet. The film and light source are controlled as a function of vehicle speed. The GERPHO system takes a continuous image of the pavement surface at speeds up to 60mph.

The inter-operation of distresses from the negative films is conducted using a viewing table and data storage operating station. The distress data is directly entered into the microcomputer using a keyboard equipped with a special template of distress codes.

3.2.3 Automatic Road Analyzer

The Automatic Road Analyzer (ARAN) vehicle was produced by Highway Products International, Inc. Ontario, Canada (Benson, 1988). An ARAN Model unit III was used in the field-testing. The ARAN measures rut depth and transverse profile with ultrasonic sensors and ride/roughness equality with the accelerometer on the rear axle. The ARAN also takes video pictures of the road right of way through the windshield and the pavement surface using a shuttered video camera behind the vehicle. It uses an on-board microprocessor to record distress data. To measure the distance to the pavement with millimeter precision at operating speeds up to 55mph, the manufacturer installed seven ultrasonic sensors on 12-inch centers, mounted in a
front bumper rut bar. To extend the rut bar width to 10, 11, and 12 feet additional sensors and bar extensions can be used. To compensate for changes of air density due to temperature variation, a calibration sensor can be used. Microprocessor-controlled, plug-in keyboards with built in liquid crystal displays, automate the collection and recording process. Dual keyboards have the capacity to handle up to twenty distresses with three-severity category.

3.2.4 Laser Road Surface Tester

The Swedish road and traffic research institute developed the Laser Road Surface Tester (RST) in 1985 (Benson, 1988). The Laser RST can reportedly measure crack depths and widths, rut depths, longitudinal profile from which roughness is computed, micro texture, cross profile, and distance. A “windshield” condition survey can also be performed by one of the operators to identify types of cracking and other distresses. The device used in the field tests has eleven bumper-mounted laser range finders and an accelerometer to measure the transverse road profile and detect cracks while traveling at speed of 18 to 55 mph. A pulse transducer, mounted on the wheel hub, measures the distance traveled by the unit.

Seven of the lasers pulse at 16 kHz and are used for the rut depth measurements. Four of the lasers pulse at 32 kHz and are used for measurement of the rut depth and cracking. Two of these lasers are used for micro texture and longitudinal profile measurements. These lasers have a reported accuracy of 0.01 inches. An onboard microcomputer integrates the sensor signals with the accelerometer and distance transducer, averages the data into manageable sections, and provides the processed data in real time. Eight three-position toggle switches are used to rate types of cracking and other distresses.
AN IMAGING INSPECTION INFORMATION MODEL FOR CONCRETE BRIDGES

In chapter 1 we talked about the inspection information system modeling methodology (see Figure 1.1). In this chapter we will focus on the first three steps of the methodology: data items analysis, conceptual data modeling and relational modeling.

4.1 Data Items Analysis

The data, which will be used in the system, will be based on the analysis of inspection forms used by MDOT, the Pontis and literature review.

4.1.1 MDOT Forms

There are two forms used by MDOT in the bridge inspection process: Bridge Inspection Field Report, and Bridge Inspection Summary Report. The first report, has the following information (see Figure 4.1):

- Bridge ID: this is a local ID given to the bridge from the MDOT.
- Facility: the road is carried by the bridge.
- Feature: what the bridge intersected with.
- Inspector Name: the name of the inspector performs the inspection.
- Inspector Key: the inspector ID who performs the inspection.
- Pontis ID: the bridge federal ID.
- Region: the region where the bridge is located.
- Date: the date of the inspection.
The second report (see Figure 4.2) has the following information:

- Facility: the road is carried by the bridge.
- Feature: what the bridge intersected with
- Location: the location of the bridge.
- Federal Structure ID: the same as the Pontis ID
- Inspector Name: the name of the inspector performs the inspection
- Agency/Consultant: the agency the inspector works for.
- Date: the date of the inspection.
- Inspector Key: the inspector ID who perform the Inspection.
- Latitude: the bridge latitude position.
- Longitude: the bridge longitude position
- Length: the length of the bridge.
- Width: the width of the bridge.
- Year Built: the year when the bridge were built.
- Year Reconstruction: the year when the bridge were reconstructed.
- Last Inspection: the last inspection date.
- Element Description: the name and description of the element.
- Rating: the rating, which describes the condition of the element.
- Inspector Comments: the inspector recommendations, and comments.
- Special Inspection Equipment: the special equipments used in the inspection.
- Inspection Method: the inspection techniques used in the inspection.
- Inspection Length: the duration of the inspection.
## Bridge Inspection Report

<table>
<thead>
<tr>
<th>Bridge Number</th>
<th>Inspector Name</th>
<th>Inspector ID</th>
<th>Pontis ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Carried</td>
<td></td>
<td></td>
<td>Region</td>
</tr>
<tr>
<td>Feature Intersected</td>
<td></td>
<td></td>
<td>Inspection Date</td>
</tr>
<tr>
<td>Location</td>
<td>Pontis Bridge Inspection</td>
<td>Old</td>
<td>New</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element Number</th>
<th>Element Name</th>
<th>Total Quant</th>
<th>State 1 Old</th>
<th>State 1 New</th>
<th>State 2 Old</th>
<th>State 2 New</th>
<th>State 3 Old</th>
<th>State 3 New</th>
<th>State 4 Old</th>
<th>State 4 New</th>
<th>State 5 Old</th>
<th>State 5 New</th>
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</tbody>
</table>

### Crew Recommendation

<table>
<thead>
<tr>
<th>Recommended Action</th>
<th>Detailed Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Patching</td>
<td>Detailed Insp.</td>
</tr>
<tr>
<td>Approach Pavement</td>
<td>Zone Paint</td>
</tr>
<tr>
<td>Joint Repair</td>
<td>Brush cut</td>
</tr>
<tr>
<td>Railing Repair</td>
<td>Substr. Repair</td>
</tr>
</tbody>
</table>

---

Figure 4.1 Bridge Inspection Field Report
## Bridge Inspection Report

<table>
<thead>
<tr>
<th>Feature</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Bridge ID</th>
<th>Last Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Length</td>
<td>Width</td>
<td>Year Built</td>
<td>Year Recon</td>
</tr>
<tr>
<td>Element Name</td>
<td>Rating</td>
<td>Comments</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Special Inspection Equipment | Method of Inspection | Inspection Length |

Figure 4.2 Bridge Inspection Summary Report
4.1.2 Pontis Data Items

Based on the study of the Pontis system, the following pieces of information are extracted:

- Element ID: Pontis Element ID, which used to identify the elements.
- Element Description: gives the complete description of the element.
- Element Rating: it is number from 0-9 describes the element condition.
- Element Rating Description: the description of the rating gives to the element.

4.1.3 Literature Review

Based on the literature review of relative bridge inspection, the following data items are extracted:

- Crack Description: describe the shape of the crack and the responses to occur.
- Crack Length: the length of the crack.
- Crack Width: the width of the crack.
- Crack Depth: the depth of the crack.
- Presence of Scaling: if there is any presence of Scaling.
- Presence of Spalling: if there is any presence of Spalling.
- Presence of Exposed Reinforcement: if there is any reinforcement exposed.
- Original Image: the image before processing.
- Cracked Image: the image after processing.

4.1.4 Final List of Data:

Based on all the previous information and after eliminating the duplication and the unnecessary data, a final list of data items is produced below:

- Bridge Number
• Facility
• Feature
• Location
• Length
• Width
• Federal ID/ Pontis ID
• Inspection Date
• Weather
• Inspector Name
• Inspector ID
• Year Built
• Element Number
• Element Description
• Condition Rating
• Condition Rating Description
• Crack Description
• Crack length
• Crack width
• Crack depth
• Presence of Scaling
• Presence of Spalling
• Presence of Exposed Reinforcement
• Original Image
• Cracked Image.
4.2 Conceptual Data Modeling

An Entity-Relationship conceptual model for the proposed image inspection information system for concrete bridge was developed using the final list of data items. Figure 4.3 shows the Entity-Relationship modeling for the imaging information system, which consists of nine entities: Bridge, Element, Date, Image, Crack, Surface Wearing, Inspector, Condition Rating, and Rating. Each entity has data items called attributes. For example the “Element” entity has two attributes: “Element ID”, and “Element Description”.

Entities are connected to each other by relationships. These relationships can be one-to-one, one-to-many, or many-to-many relation. An example of one-to-many is the relation between the “Element” entity and the “Image” entity where each element has more than one image, but each image describes a single element. An example for the one-to-one relationship is the relation between the “Inspector” and the “Rating” entities, where one inspector gives only one rating for each element in a bridge, and each element has one rating.

The letters A, B, and C in Figure 4.3 are symbols used to connect the two pages of the model.
Figure 4.3 E-R Diagram for the Imaging Information System
Figure 4.3 E-R Diagram for the Imaging Information System (Continued)
4.3 Relational Data Modeling

From the E-R diagram one can develop the relational data model. The relational model for the imaging inspection information system is shown using the following format:

Relation-name (attribute1, attribute2,..., attribute)

With the relation’s key underlined. The relational model is optimized to the 3rd normal form and consists of the following nine relations:

1- Bridge Information (Bridge ID, Federal ID, Location, Length, Width, Facility, Feature, Year Built)
2- Element Information (Element ID, Element Description)
3- Date (Date, Weather, Temp.)
4- Inspector Image (Date, Bridge ID, Element ID, Original Image, Crack Image)
5- Crack (Bridge ID, Element ID, Date, Crack Description, Crack Length, Crack Width, Crack Depth)
6- Surface Wearing (Bridge ID, Element ID, Date, Scaling, Spalling, Expose Reinforcement)
7- Inspector Information (Inspector Name, Inspector ID, Agency Consultant)
8- Element Condition Rating (Inspector ID, Bridge ID, Element ID, Date, Rating, Comment)
9- Condition Rating (Rating, Description)
This chapter focuses on the last step modeling methodology, computer modeling. Figure 5.1 shows the proposed imaging inspection information system for concrete bridges.

The system consists of three major modules:

1- Data Acquisition
2- Data Interpretation
3- Data Storage

The following subsections describe each module.

5.1 Data Acquisition

A digital camera is used to capture the bridge element images. The images are then transferred to the computer workstation for processing. During the image capturing the following factors should be considered:

1- Weather
2- Time of day
3- Shadows
4- Location of camera

Other issues that must be considered is future studies include the real time acquisition and transmission of bridge element image to a central database system. This requires investigating camera technology as well as communication mechanisms. These issues were not considered in this thesis.

5.2 Data Interpretation

After the images are downloaded into the computer, they will be processed using a crack detection technique(s) to produce the cracked images. Chapter 3 discussed some of the issues related to image processing. Once the crack images are produced they are stored in the inspection information system for further analysis.

5.3 Data Storage

Data storage is the main focus of this research. The system is an extended database designed to be integrated with Pontis as discussed earlier. The Concrete
Bridge Inspection Information program was developed using Access Software based on the relational model. It consists of four major components: Tables, Electronic Forms, Reports, and Queries. The following subsections describe each component.

5.3.1 Tables

The basic element in the database is the table where the data is stored for further manipulations to produce reports. Nine tables were developed based on the relational model. These tables are:

1- Bridge Information
2- Element Information
3- Inspection Date
4- Inspector Image
5- Detected Cracks
6- Surface Wearing
7- Inspector Information
8- Element Condition Rating
9- Condition Rating

The tables are connected to each other by physical links through the table key called. Figure 5.2 shows the database schema.
Figure 5.2 Database Schema

Figure 5.3 shows an example of a table, the Element Information table, which includes Pontis Element ID, and the Element Description. For other tables see Appendix A.
<table>
<thead>
<tr>
<th>Element ID</th>
<th>Element Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Bare Concrete Deck</td>
</tr>
<tr>
<td>13</td>
<td>Unprotected w/AC Overlay Concrete Deck</td>
</tr>
<tr>
<td>14</td>
<td>Protected w/AC Overlay Concrete Deck</td>
</tr>
<tr>
<td>18</td>
<td>Protected w/Thin Overlay Concrete Deck</td>
</tr>
<tr>
<td>22</td>
<td>Protected w/Rigid Overlay Concrete Deck</td>
</tr>
<tr>
<td>23</td>
<td>Bare Protected w/Coated Bars Concrete Deck</td>
</tr>
<tr>
<td>27</td>
<td>Protected w/Cathodic Protection Concrete Deck</td>
</tr>
<tr>
<td>35</td>
<td>Bare Precast Panel Concrete Deck</td>
</tr>
<tr>
<td>36</td>
<td>Protected w/AC Overlay Precast Panel Concrete</td>
</tr>
<tr>
<td>38</td>
<td>Bare Concrete Slab</td>
</tr>
<tr>
<td>39</td>
<td>Unprotected w/AC Overlay Concrete Slab</td>
</tr>
<tr>
<td>40</td>
<td>Protected w/AC Overlay Concrete Slab</td>
</tr>
<tr>
<td>44</td>
<td>Protected w/Thin Overlay Concrete Slab</td>
</tr>
<tr>
<td>48</td>
<td>Protected w/Rigid Overlay Concrete Slab</td>
</tr>
<tr>
<td>52</td>
<td>Protected w/Coated Bars Concrete Slab</td>
</tr>
<tr>
<td>53</td>
<td>Protected w/Cathodic Protection Concrete Slab</td>
</tr>
<tr>
<td>104</td>
<td>P/S Concrete Closed Web/ Box Girder</td>
</tr>
<tr>
<td>109</td>
<td>P/S Concrete Open Girder</td>
</tr>
<tr>
<td>110</td>
<td>Concrete Open Girder</td>
</tr>
<tr>
<td>115</td>
<td>P/S Concrete Stringer</td>
</tr>
<tr>
<td>116</td>
<td>Concrete Stringer</td>
</tr>
<tr>
<td>143</td>
<td>P/S Concrete Arch</td>
</tr>
<tr>
<td>144</td>
<td>Concrete Arc1</td>
</tr>
<tr>
<td>154</td>
<td>P/S Concrete Floor Beam</td>
</tr>
<tr>
<td>155</td>
<td>Concrete Floor Beam</td>
</tr>
<tr>
<td>205</td>
<td>Concrete Column</td>
</tr>
<tr>
<td>210</td>
<td>Concrete Pier Wall</td>
</tr>
<tr>
<td>215</td>
<td>Concrete Abutment</td>
</tr>
<tr>
<td>241</td>
<td>Concrete Culvert</td>
</tr>
<tr>
<td>321</td>
<td>P/S Concrete Approach Slab</td>
</tr>
<tr>
<td>331</td>
<td>Concrete Bridge Railing</td>
</tr>
<tr>
<td>340</td>
<td>Superstructure Concrete Coating</td>
</tr>
<tr>
<td>341</td>
<td>Substructure Concrete Coating</td>
</tr>
</tbody>
</table>

Figure 5.3 Element Information Table
5.3.2 Electronic Forms

For easier use of the program and to make it more user friendly, electronic forms were developed for data entry. An electronic form was developed for each table. Figure 5.4 shows the Bridge Information Form, which is used to enter data into the Bridge Information table. This form includes all the information related to a bridge such as the Bridge ID, Federal ID, Location, Year Built, and other information.

![Bridge Information Form](image)

Figure 5.4 Bridge Information Form

In Figure 5.5 one can see the Element Information Form, which includes the Element ID and Element Description. This form is used to enter data into the Element Information table.
Figure 5.5 Element Information Form

Figure 5.6 Condition Rating Form

Figure 5.6 shows the Condition Rating Form, which includes both the rating and the description.
In Figure 5.7 illustrates see the Inspector Information Form, which has the Inspector ID, Inspector Name and the Inspector Agency.

![Inspector Information Form](image)

**Figure 5.7 Inspector Information Form**

Figure 5.8 shows the Inspector Image Form, which is used to enter both original image and the cracked image. It is also, used by the inspector later to rate the element.

Figure 5.9 shows see the Detected Cracks Form where the inspector enters the identified crack description.

Figure 5.10 illustrates the Surface Wearing Form. This form shows the information the inspector extracted from the images regarding any surface wearing for such as Scaling, and Spalling.
Figure 5.8 Inspector Image Form
Figure 5.9 Detected Cracks Form

Figure 5.10 Wearing Surface Form
5.3.3 Reports

The Reports module is the final component of the system. This system includes three different reports:

- Bridge Inspection Daily Report.
- Element Inspection History Report
- Bridge Inspection History Report.

Figure 5.11 shows the Bridge Inspection Daily Report, which has all the information for a bridge, such as inspector, date of inspection, elements, and elements rating.

Figure 5.12 shows the Element Inspection History Report, which includes all the available data regarding an element in a bridge between two dates.

![Bridge Inspection Daily Report](image)

**Figure 5.11 Bridge Inspection Daily Report**
Figure 5.12 Element Inspection History Report

Figure 5.13 is the Bridge Inspection History Report. In this report all the information available regarding bridge inspection between two dates. See figure 5.13.
### Bridge Inspection History Report

<table>
<thead>
<tr>
<th>Bridge ID</th>
<th>Federal ID</th>
<th>Location</th>
<th>Year Built</th>
<th>Feature</th>
<th>Facility</th>
<th>Length</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>87</td>
<td>03103021000020</td>
<td>8 MI E OF Fennville</td>
<td>1950</td>
<td>Kalamazoo River</td>
<td>M-89</td>
<td>359.90</td>
<td>35.10</td>
</tr>
</tbody>
</table>

**Element ID:** 12

**Element Description:** Bare Concrete Deck

<table>
<thead>
<tr>
<th>Date</th>
<th>Rating</th>
<th>Comment</th>
<th>Inspector ID</th>
<th>Inspector Name</th>
<th>Agency Consultant</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/23/2002</td>
<td>6</td>
<td>Poor Condition</td>
<td>mtdb</td>
<td>Mohammed</td>
<td>WMU</td>
</tr>
</tbody>
</table>

**Element ID:** 14

**Element Description:** Protected w/AC Overlay Concrete Deck

<table>
<thead>
<tr>
<th>Date</th>
<th>Rating</th>
<th>Comment</th>
<th>Inspector ID</th>
<th>Inspector Name</th>
<th>Agency Consultant</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/14/2000</td>
<td>2</td>
<td>Very Good Condition</td>
<td>mtdb</td>
<td>Mohammed</td>
<td>WMU</td>
</tr>
<tr>
<td>8/21/2001</td>
<td>3</td>
<td>Good Condition</td>
<td>JNMR</td>
<td>Curtis Liu</td>
<td>SW Region</td>
</tr>
<tr>
<td>5/25/2001</td>
<td>3</td>
<td>Good Condition</td>
<td>JNMR</td>
<td>Curtis Liu</td>
<td>SW Region</td>
</tr>
<tr>
<td>5/25/2000</td>
<td>2</td>
<td>Very Good Condition</td>
<td>mtdb</td>
<td>Mohammed</td>
<td>WMU</td>
</tr>
<tr>
<td>5/23/2002</td>
<td>4</td>
<td>Satisfactory Condition</td>
<td>mtdb</td>
<td>Mohammed</td>
<td>WMU</td>
</tr>
</tbody>
</table>

---

**Figure 5.13 Bridge Inspection History Report**

5.3.4 Queries

Queries are the internal data manipulation functions used to perform calculations on the stored data. In addition to that, further filtration could be applied on the results. The results of the queries could be used as a report. An example is shown in Figure 5.14.

**Figure 5.14 Inspector Image Query**

This query includes the Images for the specific element in a bridge, related by the Bridge ID, Element ID, and Date. For other queries see Appendix B.
5.4 User Interface

This section describes the user interface components of the system. Basically, the program consist of four major parts as follow (see Figure 5.15):

1- The main menu “Concrete Bridge Inspection System Form”
2- Data Entry Forms
3- Inspector Reports
4- Inspection Summary Reports

The following subsections give a brief description of each part.

Figure 5.15 Menu Schematic Tree
5.4.1 The Main Menu

This is the first part of the system. One can find it under the name of Concrete Bridge Inspection System Form, see figure 5.16.

As we can see there are two choices for making: Data Entry Forms, and Inspection Summary Report. By clicking on each one, a new form will appear and this form will disappear.

5.4.2 Data Entry Forms

To enter new data, the user can click on Data Entry Forms, to open the Data Entry Forms Form (see figure 5.17). This form includes six choices to select from simply by clicking on any of them; those forms are Bridge Information, Condition Rating, Element Information, Inspector Information, Inspector Image, and Inspector...
Image Analysis. The most tricky entry data will be the inspector image, because the data will be entered as an object. What the user needs to do is to select the field for the image, then click on the Insert on the main menu after that select the object. Or, one can click on the right click using the mouse and choose to add an object. When finished you can return to the main menu or exit by clicking “back” or “End” respectively.

By clicking on the Inspector Image Analysis, you will run a query, which will require the following information:

- Bridge ID
- Element ID
- Date

The result will be on the Inspector Image Query form (see Figure 5.19). This form will include both the original image and the cracked image 'produced by running the original image through the image processing techniques' for the element. Each element may have more than one picture. Note that element may have more than one picture.

5.4.3 Inspector Reports

After the inspector manipulates the pictures and extracts the results, he can go to the Inspector Reports menu, which includes three entry forms (see Figure 5.18). After entering the data, he can go back or see the next element. The Inspector Reports menu includes Detected Cracks Form (see Figure 5.9), Surface Wearing Form (see Figure 5.10), and the Element Condition Rating Form (see Figure 5.20).
Figure 5.17 Data Entry Forms

Figure 5.18 Inspector Reports Form
Figure 5.19 Inspector Image Query Form
5.4.4 Inspection Summary Reports

This is the final part of the system where the results are displayed in reports (see Figure 5.21). In this menu there are three different reports: Bridge Daily Inspection Report, Element Inspection History Report, and Bridge Inspection History Report. To run the first report you need Bridge ID and Date. The report will shows all the inspection activities which occurred on that day on the specified bridge. For the second report you need Bridge ID, Element ID, Date1, and Date2. The result will show all the inspection history for the element during the specified period of time. The last report requires Bridge ID, Date1, and Date2. This report provides all the inspection activities for the bridge during a specified period of time.
Figure 5.21 Inspection Summary Reports Form
6.1 Conclusion

In this research project a new imaging inspection information system for concrete bridge was created to replace visual inspection. Inspection is an important part of bridge life-cycle. It helps keep the bridge at an acceptable level of performance and safety. Also, it provides the decision maker with the proper information to make a maintenance decision at the appropriate time.

Visual inspection, which is the primary method for bridge inspection, is subjective and does not provide an accurate assessment of the bridge condition. Additionally, this method is slow, qualitative, and potentially hazardous for the inspector. The Imaging Inspection Information System for concrete bridges was developed based on image processing techniques in an attempt to provide more reliable and automated techniques for condition assessment. The bridge element images have been collected by digital camera and processed using edge detection to create the cracked images that are used by the inspector to evaluate the element without being subjected to any hazardous situations. This increases the safety of the inspection process and provides a faster method for inspection. Also, the data can be revisited and viewed several times since it is stored in the system. Furthermore, it is recommended that the system eventually includes an automated analysis module using image processing techniques.

Pontis is a comprehensive bridge management system developed as a tool to assist in the challenging task of bridge management. Pontis stores bridge inventory
and inspection data and formulates network wide preservation and improvement policies for use in evaluating the needs of each bridge in a network. The research project described in this thesis extends the scope of Pontis by adding the automated inspection methodology. This extension of scope was achieved through the integration of the inspection information system using Pontis elements.

6.2 Future Research

This research project focused on creating a concrete bridge information model and system for bridge inspection using imaging data. More work needs to be directed towards the data interpretation phase. The automation of the data interpretation can be achieved using image processing techniques that can isolate cracks and reason about the attributes of these cracks such as width, depth, length, etc. Further analysis and automated techniques can also help identify the types of surface defects.
BIBLIOGRAPHY


Pontis Bridge Inspection Coding Guide (October 1998)


Available at: [http://iti.acns.nwu.edu/pubs/shubin.html](http://iti.acns.nwu.edu/pubs/shubin.html).


APPENDICES
Appendix A

Concrete Bridge Inspection Information System Set of Tables
Figure A.1 Bridge Information Table

Figure A.2 Condition Rating Table

Figure A.3 Detected Cracks
Figure A.7 Date Table

<table>
<thead>
<tr>
<th>Date</th>
<th>Weather</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/22/2000</td>
<td>rain</td>
<td>59</td>
</tr>
<tr>
<td>6/9/2000</td>
<td>hot</td>
<td>69</td>
</tr>
<tr>
<td>5/21/2002</td>
<td>Fare</td>
<td>63</td>
</tr>
<tr>
<td>5/23/2002</td>
<td>Fare</td>
<td>67</td>
</tr>
</tbody>
</table>

Figure A.8 Inspection Image

<table>
<thead>
<tr>
<th>Bridge ID</th>
<th>Element ID</th>
<th>Date</th>
<th>Original Image</th>
<th>Cracked Image</th>
<th>Weather</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>87</td>
<td>13</td>
<td>5/23/2002</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>13</td>
<td>5/23/2002</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>533</td>
<td>13</td>
<td>5/23/2002</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>14</td>
<td>5/23/2002</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
<td>Microsoft Photo Editor 3.0 Photo Microsoft Photo Editor 3.0 Photo fair</td>
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Appendix B

Concrete Bridge Inspection Information System Set of Quires
**Figure B.1 Bridge Inspection Daily Query**

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**Figure B.2 Bridge Inspection History Query**

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**Figure B.3 Element Inspection History Query**

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