IMPROVEMENT OF CONCRETE PIPE CULVERT RATINGS
USING AN EXPERT SYSTEM

A Thesis

Presented in Partial Fulfillment of the Requirements for the degree Master of Science in the Graduate school of the Ohio State University

by

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* * * * *

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To My Parents
ACKNOWLEDGMENTS

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CHAPTER I
INTRODUCTION

1.1 Ratings of Concrete Culverts

Concrete pipe culverts play an important role in the drainage of highways and railways. While it is often difficult and costly to replace a culvert, timely replacement is essential in order to protect the public safety. On the other hand, premature replacement leads to unnecessary replacement, inconvenience, and higher costs.

Culverts are regularly inspected to assure timely repair or replacement. Data from the field is used to "rate" culverts. Ratings can be used to predict when culverts will need to be repaired or replaced. In turn, repair and replacement programs can be developed by transportation departments to assure the safety of the public and to minimize the cost of repairing or replacing culverts.

Several studies presented by various states show conflicting and inconsistent conclusions about important variables affecting concrete culvert ratings. However, these states have distinct environmental conditions, which lead to different variables that determine the rating of
the concrete pipe. Thus, the concrete ratings obtained from regression analysis are different for each state. However, the procedure for collecting data and rating culverts is similar from state to state.

An inspector who is specially trained must go out into the field to inspect and collect the necessary information so that a concrete rating equation can be used. After the necessary information has been collected, one may enter the data into the equation to yield the concrete rating. As an example, for pH=3, Slope=2.5%, Age=10 years and Rise=48 inch, the state of Ohio [17] predicted the condition of a culvert to be in the VERY POOR range. With everything the same except the pH=7, the condition of the culvert is in the GOOD range. Therefore, the data has a significant effect on the calculated rating.

The field inspector can also judge the culverts based on his/her observations of the concrete conditions. Ratings based on such observations might be different than the calculated ratings. This is quite understandable, but the question is, how can one combine conflicting ratings to improve culvert assessments?

This thesis proposes a technique for developing an expert system which will improve concrete ratings by using both the inspector's judgments and the field data. If the expert system is successfully developed, the Department of
Transportation will be able to minimize the cost of repair and replacement while maintaining safe highways and railways.

1.2 Expert Systems

Expert systems are widely used in many areas such as medical diagnosis, structural analysis, structural failure diagnosis and education. An expert system is a representation of professional knowledge and is used as a tool to solve complicated problems. An expert is one who has worked in the subject area many years so that he/she can accumulate the various knowledge over time. The expert would not have to be called in to solve the problems since his/her knowledge is stored in the computer which can be used to solve the problems.

The expert's knowledge can come from facts and heuristics. For instance, one can use the American Concrete Institute (ACI) code as facts for the expert system. The heuristics are so called "common sense" developed by experts over the years. The combination of facts and heuristics is an essential tool for the expert system.

The greatest advantage of using the expert system is that it preserves the expert's knowledge. Very often, experts' judgments are lost when these people retire. But person's knowledge can be easily stored in the computer.
The computer memory storage area is not a problem for today's advanced computer technology. Also, the knowledge can be added to or revised easily when there is more information available. Another advantage is the ease of using the expert system by those who have very little information about a culvert. It is even more helpful to those inspectors who are very familiar with the culvert but need additional assistance to make final judgments about the culverts. Using an expert system will save a great deal of time and money because it is very expensive to hire a professional to make judgments about every culvert. Also there are not many experts in this field.

In order to use an expert system, it is necessary to collect the professional's knowledge. In some cases, it is very time consuming to send questionnaires to these persons so that their opinions and knowledge can be collected. Unfortunately, it may take months to complete the questionnaires. Sometimes, the experts' evaluation of subjective judgment differs from one person to another.

But despite such drawbacks associated with expert systems, the advantages are far greater than the disadvantages.
1.3 Major Objective of this Thesis

The main objective of this thesis is to develop an expert system to obtain better culvert ratings. Four kinds of information will be used in the expert system: 1) observations of the culvert condition using linguistic values; 2) quantitative field data; 3) inspector judgments; and 4) supervisor weightings. By combining these four kinds of information, instead of just using inspector's observations, concrete ratings can be improved. The reasons for combining this information are: 1) to resolve potential discrepancies among inspector's judgments, the calculated ratings, and ratings based on state Department of Transportation (DOT) rules; and 2) to try to eliminate the uncertainty of inspector judgment, the analysis or the DOT rules.

Very often, inspectors use their subjective judgments to rate culverts. The inspection rating may conflict with the calculation rating. The discrepancy creates great confusion especially if the calculated rating is GOOD and the Inspected rating is POOR. This is very likely to happen because of different times and seasons will present varying field data which will change the calculated rating. Also, the DOT evaluation scale may not agree with other ratings. Moreover, the inspector's subjective ratings may differ from one another. Therefore, a better
rating can be obtained by combining the inspector's rating with the calculated rating and DOT's rules.

The ability of an inspector to judge a concrete culvert depends on the experience and the training he/she has obtained over the years. Obviously some inspectors can give more accurate ratings than others; therefore the inspector rating is an uncertain factor. Also, the analysis and the rules from DOT rely on the precision of the description for each rating.

It is essential to have the correct rating of the culvert because if good concrete is given a bad rating, the culvert will be replaced. Such an act is unnecessary and costly. Also, if bad concrete is given a good rating, the culvert might fail before maintenance can be done. Therefore, the concrete rating should be improved so that the actual rating can be obtained.

1.4 Scope

This thesis only considers concrete pipe culverts. The type of failure is limited to material failure or deterioration.

The author intends to use the State of Ohio evaluation scale [17] for qualitative ratings.

For quantitative ratings, a regression equation for 4 variables based on 399 observations will be used. The equation is obtained from the study done by Hadipriono
1.5 Organization of this Thesis

Chapter 2 deals with the factors affecting concrete pipe ratings. In Chapter 3, the technique of developing an expert system is introduced. The major components of the expert system are also presented in this chapter. The method of combining the four ratings are discussed in Chapter 4. The procedure for creating a new expert system using the EXSYS shell is included in Section 4.2. The conclusions and recommendations are in Chapter 5.

A detailed procedure for using the expert system is shown in Appendix A and B. Two sample problems are chosen to run the expert system. Additional samples are shown in Appendix C.
CHAPTER II
FACTORS AFFECTING CONCRETE PIPE RATING

2.1 Introduction

Culverts will be replaced when significant concrete deterioration takes place. However, maintenance is always needed to prolong the service life of concrete. Therefore, regular inspections of concrete culverts are designed to check against any abrupt changes of field conditions, which in turn will change the concrete rating of culverts. It will not be a surprise to see the rating alter when the field conditions change with different field inspections.

Concrete pipe culvert deterioration can be explained by the occurrence of the enabling and triggering events. Usually material failure takes place when both enabling and triggering events occur at the same time [7,8]. Structural failure is beyond the scope of this study. An enabling event is a deficiency in the design or construction of the culvert. For instance, improper sealing of a construction joint is an enabling event. A triggering event is an external event such as a high
sulphate content in the water or the soil. The following enabling and triggering events (not exhaustive) are known to cause concrete deterioration.

2.2 Enabling Events in Concrete Pipe Deterioration

The enabling events in concrete pipe deterioration are: 1) inadequate compressive strength of concrete; 2) improper/insufficient use of admixtures; and 3) improper use of cement.

2.2.1 Inadequate compressive strength of concrete

The minimum concrete strength required is 4000 to 6000 pounds per square inch and can reach 8000 pounds per square inch after 28 days [3]. Generally, the strength is related to the structural integrity. Very often, low compressive strength suffers deterioration because of abrasion and chemical attack. Therefore, it is very important to achieve the correct strength.

2.2.2 Improper/insufficient use of admixtures

Admixtures are added to improve the quality of the concrete. Common admixtures are air entrainment, water reducing and accelerating agents.

The air entrainment agent provides bubbles in the concrete to release the pressure of volume change, thus reducing damage. The omission of the air entrainment
agent can be a very serious problem when the culvert is exposed to severe freeze and thaw cycles. The state of Kansas study [13] concluded that if the air entrainment agent is not used for a culvert, then the concrete will be completely scaled through the pipe invert within ten winters. The agent causes a slight reduction in the compressive strength of concrete, but it greatly increases the freeze and thaw resistance. Ropke [24] recommended the use of the normal dosage of 1 fl oz/100 lb. of cement.

The water reducing agents are used to reduce the water content of the given slump while increasing the water-cement ratio. Two to three fl oz/100 lb. of water reducing agent should be added to the concrete.

Set accelerating agents are used to reduce the time setting and to increase the high early strength of concrete. This agent is frequently used in cold weather when earlier finishing is desired. Calcium Chloride is commonly used in this agent. Unfortunately, calcium chloride is known to cause corrosion of concrete reinforcement if not properly utilized. Therefore many designs restrict the use of this agent. Additionally, calcium chloride also reduces the freeze and thaw resistance, and increases the drying shrinkage. If this agent must be used, a maximum of 1.5 percent by weight of the cement is recommended [23].
2.2.3 Improper use of cement

There are five common types of cement used in making concrete. The type of cement used in the concrete is an important factor in a culvert. For instance, in a high sulphate content area, Type II or Type V cement should be used. The use of the wrong kind of cement may result in a poor rating after a few years. Table 1 shows the cement types and their purposes. Very often, admixtures are added to the concrete for special purposes.

Table 1 Cement Types and their Purposes [20]

<table>
<thead>
<tr>
<th>TYPE</th>
<th>NAME</th>
<th>PURPOSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Normal Portland Cement</td>
<td>General purpose cement</td>
</tr>
<tr>
<td>II</td>
<td>Modified Portland cement</td>
<td>Moderate sulphate attack</td>
</tr>
<tr>
<td>III</td>
<td>High Early Strength Portland Cement</td>
<td>High early strength is required</td>
</tr>
<tr>
<td>IV</td>
<td>Low Heat Portland Cement</td>
<td>Low heat of hydration is required</td>
</tr>
<tr>
<td>V</td>
<td>Sulphate Resistant Portland cement</td>
<td>Severe Sulphate Attack</td>
</tr>
</tbody>
</table>
2.3 Triggering Events in Concrete Pipe Deterioration

Triggering events are the most discussed issue in this study because they deal with the external events. In this study, the external events are the field conditions which may affect the life of the culverts. The triggering events in concrete pipe deterioration are: 1) acid attack, 2) sulphate attack, and 3) velocity of the water.

2.3.1 Acid attack

The degree of aggressiveness of acid is measured by the pH, which is defined as the logarithm of the hydrogen ion concentration of a solution. It ranges from 0 to 14 with 7 being neutral (water). The acid is classified as less than 7 and the alkaline is above 7. Table 2 shows how acid or alkaline compares with water. Acid is the most mentioned factor affecting the rating of the concrete [3,5,11,12].

From Table 2, a pH = 5 is 100 times as acidic as a pH=7. There are three common methods to determine the pH in the field: the pH meter, comparison box, and titration paper. The study performed by the State of Utah [26] indicated that the pH meter is the more accurate method to determine the pH in the field. Accuracy is important in determining the pH since it will have a significant effect on later determination of the concrete rating.
Corrosion of concrete and steel rebars is highly affected by the acidity, especially when the pH is less than 5. This finding was obtained through research from various states. For instance, the State of Kentucky [12] showed that if the pH is less than 3, the deterioration rate is four times as great as when the pH level of 7.

Table 2 The pH Scale [4]

<table>
<thead>
<tr>
<th>pH value</th>
<th>Number of times of Acidity or Alkalinity exceeds that of pure water (pH=7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>0</td>
<td>10,000,000</td>
</tr>
<tr>
<td>1</td>
<td>1,000,000</td>
</tr>
<tr>
<td>2</td>
<td>100,000</td>
</tr>
<tr>
<td>3</td>
<td>10,000</td>
</tr>
<tr>
<td>4</td>
<td>1,000</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>1,000</td>
</tr>
<tr>
<td>11</td>
<td>10,000</td>
</tr>
<tr>
<td>12</td>
<td>100,000</td>
</tr>
<tr>
<td>13</td>
<td>1,000,000</td>
</tr>
<tr>
<td>14</td>
<td>10,000,000</td>
</tr>
</tbody>
</table>
In order to avoid or to reduce the acid attack on the concrete and the rebars, low permeable materials, calcareous materials, protective coatings and increased concrete cover are used to neutralize the acids.

2.3.2 Sulphate attack

Sulphate attacks are from the groundwater, soil and effluent with sodium, magnesium, and calcium sulphate [3]. The chemical may react with calcium alumica (C₃A) to cause concrete expansion and spalling. The degree of severity of sulphate attacks is shown in Table 3. Very often, a designer may choose to use Type II or Type V cement (depending on the sulphate content) to deal with this problem. Also, reducing the C₃A contents in concrete, applying steam curing, and increasing the absorption factor can reduce the sulphate attacks. In California, the guidelines presented in Table 4 are used to combat sulphate attack.
Table 3  Attack on Concrete by Soil and Waters Containing Various Sulphate Concentrations [2]

<table>
<thead>
<tr>
<th>Relative Degree of Sulphate Attack</th>
<th>Percent Water-soluble Sulphate (as SO₄) in Soil Samples</th>
<th>PPM Sulphate (AS SO₄) in Water Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>0.00 to 0.10</td>
<td>0 to 150</td>
</tr>
<tr>
<td>Positive*</td>
<td>0.10 to 0.20</td>
<td>150 to 1500</td>
</tr>
<tr>
<td>Severe**</td>
<td>0.20 to 2.00</td>
<td>1500 to 10000</td>
</tr>
<tr>
<td>Very Severe***</td>
<td>2.00 or more</td>
<td>10000 or more</td>
</tr>
</tbody>
</table>

* Use Type II cement.
** Use Type V cement, or approved portland-pozzolan cement provided comparable sulphate resistance when used in concrete.
*** Use Type V cement plus approved pozzolan which has been determined by test to improve sulphate resistance when used in concrete with Type V cement.

Table 4  Guide for Sulphate Resistant Concrete Pipe and other Concrete Drainage Structures[5]

<table>
<thead>
<tr>
<th>Water-soluble sulphate (SO₄) in soil sample (percent)</th>
<th>Sulphate (SO₄) in water sample (percent)</th>
<th>Type of cement</th>
<th>Cement factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.2</td>
<td>0-2000</td>
<td>II</td>
<td>Minimum required by specifications</td>
</tr>
<tr>
<td>0.2-0.5</td>
<td>2000-5000</td>
<td>V</td>
<td>Minimum required by specifications or II 7 sacks **</td>
</tr>
<tr>
<td>0.5-1.5</td>
<td>5000-15000</td>
<td>V</td>
<td>Minimum required by specifications or II 7 sacks</td>
</tr>
<tr>
<td>over 1.5</td>
<td>over 15000</td>
<td>V</td>
<td>7 sacks</td>
</tr>
</tbody>
</table>

* Recommended measures for cement type and factor based on sulphate content of soil and water (California7-851.3d)
** 7-sack cement = 390 kg of cement/cm³ of concrete.
2.3.3 Velocity of the water

Abrasion is defined by the ACI committee as the wearing away of a surface by rubbing or the friction process. Abrasion will not cause a problem unless the flow velocity of the pipe is greater than 40 feet per second, and the concrete surface is not smooth [3]. Also, if the joints are not sealed properly, abrasion can be very serious. The problem of abrasion can be limited by increasing the compressive strength and the quality of concrete.

2.4 Protective Coatings

Protective coatings are applied to the concrete when it is over exposed to chemical attacks from acids, sulphate, or chloride. Sometimes, they are used for repairing the concrete when scaling or spalling are severe. The effectiveness of the coatings is dependent upon the usage. For instance, the cement mortar coatings are used for repairing the concrete. The cost of the mortar is very high due to installation costs. The common coatings used in culverts are:

1. Asphalt,
2. Mortar,
3. Fiberglass,
4. Bituminous,
5. Asbestos Impregnated Bituminous, and
6. Vitrified Clay Linear Plates.
2.5 Rating of the Concrete Pipe

Usually, the rating of a culvert is provided by an inspector based on his/her visual field inspection. An inspector must be well trained to distinguish between different kinds of deterioration. In this study, the concrete rating is also determined from various information.

The inspectors usually use subjective ratings such as "good" or "poor" to indicate the condition of the concrete pipe. However, different inspectors might have different opinions about the ratings. As a result, many states set their own evaluation scale to distinguish the ratings. Tables 5 and 6 present examples of visual rating scales from the State of Ohio. As one can see from the tables, a clear and precise description of ratings is necessary to enhance the accuracy of pipe deterioration assessments. For instance, the State of Ohio (Table 5) pairs "excellent" with the number 1. The "excellent" condition is concrete as constructed.

The next chapter describes the Expert System which will be used to improve concrete ratings.
### Table 5  Ohio Concrete Pipe Evaluation Scale [17]

<table>
<thead>
<tr>
<th>Rating</th>
<th>Linguistic Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>1</td>
<td>Excellent</td>
<td>A. Condition of concrete as constructed</td>
</tr>
<tr>
<td>2</td>
<td>Very Good</td>
<td>A. Discoloration but no loss, corrosion or softening</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
<td>A. Slight loss of mortar leaving aggregate exposed.</td>
</tr>
<tr>
<td>4</td>
<td>Fair</td>
<td>A. Moderate loss of mortar and aggregate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Slight softening of concrete.</td>
</tr>
<tr>
<td>5</td>
<td>Poor</td>
<td>A. Significant loss of mortar and aggregate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B. Complete loss of invert.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C. Concrete in softened condition.</td>
</tr>
</tbody>
</table>

### Table 6  Concrete Pipe Ratings [14]

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description of condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>0</td>
<td>As manufactured</td>
</tr>
<tr>
<td>10</td>
<td>Slight loss of mortar, aggregate not exposed</td>
</tr>
<tr>
<td>20</td>
<td>Moderate loss of mortar, aggregate exposed</td>
</tr>
<tr>
<td>30</td>
<td>Significant loss of mortar around aggregate</td>
</tr>
<tr>
<td>40</td>
<td>Significant loss of mortar, slight aggregate loss</td>
</tr>
<tr>
<td>50</td>
<td>Moderate aggregate loss (part of &quot;1st. layer&quot;)</td>
</tr>
<tr>
<td>60</td>
<td>Significant aggregate loss (all of &quot;1st. layer&quot;)</td>
</tr>
<tr>
<td>70</td>
<td>Severe aggregate loss (into &quot;2nd. layer&quot;)</td>
</tr>
<tr>
<td>80</td>
<td>Reinforcing exposed at a few places</td>
</tr>
<tr>
<td>90</td>
<td>Reinforcing exposed throughout pipe</td>
</tr>
<tr>
<td>100</td>
<td>Reinforcing gone</td>
</tr>
</tbody>
</table>
CHAPTER III

TECHNIQUE OF IMPROVING CULVERT RATINGS

BY USING AN EXPERT SYSTEM

3.1 Architecture of Improving Culvert Rating

by Using an Expert System

In this study, the expert system is intended to be used with the IBM micro-computer. With today's advanced micro-computer technology, the data storage area which is essential to the expert system is not a problem. Thus, the micro-computer is very useful to improve Culvert Ratings by using an Expert System (CRES). The micro-computer hardware is beyond the scope of this study, but the major components of CRES consist of 6 parts which are show in Figure 1. These parts are:

1. Past history,
2. Knowledge base,
3. Data base,
4. Inference mechanism,
5. Knowledge acquisition and Explanations, and
6. Computation mechanism.

The arrow in Figure 1 indicates how each component interact with others. For instance, the data base will
send information to the inference mechanism and past history. But it only accepts information from the inference mechanism.

3.2 Past History

The past history should consist of the past inspection records. The inspector can check the field conditions against the past records to see if any abrupt changes in the field have occurred. If there are any major changes, the inspector should determine the source, such as a new factory near the culvert which may be dumping chemicals into the concrete pipe. Unfortunately, many records needed in this thesis are missing and valuable information is often simply unrecorded, which makes the study more difficult. The author recommends that all the data should be kept in the computer for future use. Past records must also be stored in a permanent area.
Figure 1. Architecture of CRES
3.3 Knowledge Base

The knowledge base of the CRES contains the professional judgments on concrete culvert pipes. The expert gives opinions based on the condition of the concrete culvert. For instance, when an expert knows that the concrete has only slight loss of mortar and the aggregate is exposed, he/she will give the concrete a certain rating. Therefore, the experts opinions are very important because the ability of the CRES to solve a problem depends on this knowledge. The knowledge base should be able to allow for the easy updating of new knowledge. The knowledge is represented by production rules which have been discussed in the literature [1,16,18,19,25].

3.3.1 Production rules

The expert knowledge is stored in the computer, which is represented by the production rules. The format of the production rule is simple and easy to update when new information is gathered. It follows the form of "IF ... THEN." For instance,

IF:

- CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
- DISCOLORATION BUT NO LOSS, CORROSION OR SOFTENING IS FALSE
- SLIGHT LOSS OF MORTAR IS TRUE
- AGGREGATE EXPOSED IS TRUE
- MODERATE LOSS OF MORTAR IS FALSE
- MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN

THE QUALITATIVE RATING IS GOOD

Knowing that the qualitative rating is GOOD, one still has to find the quantitative rating, inspector rating and supervisor weighting, all of which will be explained in Chapter IV.

3.3.2 Organization of the knowledge structure

The organization of the knowledge structure consists of four parts as shown in Figure 2. The first part is the inspectors' observations of the concrete culvert, which yield the qualitative rating. The second part is the field data analysis using the regression equation to obtain the quantitative rating. The third part is the inspector's own judgment on the culvert rating. Finally, there is the supervisor weighting on the above ratings. Consequently, the final concrete culvert rating is derived based on the above information.
Figure 2. Organization of Knowledge Structure.
3.4 Data Base

The inspector is responsible for gathering the field data and observing the culvert. The data and the observation will help the CRES in determining the condition of the culvert.

The CRES requests information from the user in order to collect information about the culvert. This information consists of three parts: 1) Inspector Observations / Rating, 2) Testing, and 3) Measuring.

3.4.1 Inspector observations / rating

The inspector needs to give judgments on the culvert based on the ODOT evaluation scale, which is listed in Table 7. When the inspector enters the information needed to execute the CRES, the qualitative rating is produced. Since the inspector is the one who studied the culvert, his/her judgment should also be included. Should there be any contradiction later, CRES will be handle the discrepancy.
Table 7  Parameters for Inspector Observations

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CHOICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONDITION OF CONCRETE AS CONSTRUCTED IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>DISCOLORATION BUT NO LOSS, CORROSION OR SOFTENING IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>SLIGHT LOSS OF MORTAR IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>AGGREGATE EXPOSED IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>MODERATE LOSS OF MORTAR IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>MODERATE LOSS OF AGGREGATE IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>SLIGHT SOFTENING OF CONCRETE IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF MORTAR IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF AGGREGATE IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>COMPLETE LOSS OF INVERT IS</td>
<td>TRUE/FALSE</td>
</tr>
<tr>
<td>CONCRETE IN SOFTENED CONDITION IS</td>
<td>TRUE/FALSE</td>
</tr>
</tbody>
</table>

3.4.2 Testing

Testing is required to determine the acidity of the water since acidity is a major influence on the culvert. The acid can deteriorate the culvert significantly, which in turn damages the pipe. The condition of the pipe will be poor with low acid content. Table 8 shows the parameters for testing.

Table 8  Parameters of Testing

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td>0 &lt;= PH &lt;= 14</td>
</tr>
</tbody>
</table>
3.4.3 Measuring

The flow depth (FDEPTH), the sediment depth (SDEPTH), and the flow velocity (FVEL) can be measured during the inspection. The FDEPTH and the SDEPTH are in the INCH unit, and the FVEL is the subjective rating. Table 9 lists the parameters for measuring.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDEPTH</td>
<td>NUMERICAL VALUE</td>
</tr>
<tr>
<td>FDEPTH</td>
<td>NUMERICAL VALUE</td>
</tr>
<tr>
<td>FVEL</td>
<td>INTEGER VALUE</td>
</tr>
</tbody>
</table>

3.5 Inference Mechanism

The inference mechanism determines which production rules are to be used when utilizing the CRES. The CRES uses the rules in the knowledge base, user input from the data base, and the data from the past history to determine the condition of the culvert. This system also provides a certainty factor for each conclusion. Therefore, one must be extremely careful when making the rules. We must avoid rules that have the same antecedent but different conclusions.
3.5.1 Method of inferencing

Figure 3 shows the method of inferencing for the CRES. Basically, it determines the inspector observations (qualitative), the rating from the field data (quantitative), the supervisor weighting, and the inspector rating to draw the final conclusion of the culvert. For example,

IF : CONDITIONS OF CONCRETE AS CONSTRUCTED IS FALSE
    and DISCOLORATION BUT NO LOSS, CORROSION OR
    SOFTENING IS FALSE
    and SLIGHT LOSS OF MORTAR IS FALSE
    and AGGREGATE EXPOSED IS FALSE
    and MODERATE LOSS OF MORTAR IS TRUE
    and MODERATE LOSS OF AGGREGATE IS TRUE
    and SLIGHT SOFTENING OF CONCRETE IS TRUE
    and SIGNIFICANT LOSS OF MORTAR IS FALSE
    and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
    and COMPLETE LOSS OF INVERT IS FALSE
    and CONCRETE IN SOFTENED CONDITION IS FALSE
THEN
THE QUALITATIVE RATING IS FAIR

By knowing the qualitative rating, the computer will need to know the quantitative rating.

IF:

\[ \text{2.66667 < [RATE]} \]

\[ \text{[RATE]} \leq 3.33333 \]

THEN

THE QUANTITATIVE RATING IS GOOD

To combine both ratings, the computer also needs the inspector rating and the supervisor weighting so that the final concrete rating can be determined. In a later section, the computation method will be shown. A certainty factor will also be assigned to the final conclusion.
Field data from test and measurement

QNR is determined

Inspector observations on the condition of the culvert

QLR is determined

Inspector's rating based on his/her own opinion.

INR is determined

Supervisor weighting

Final concrete rating is determined

Figure 3. Method of Inferencing
3.6 Knowledge Acquisition and Explanations

3.6.1 Knowledge acquisition

The most important component of the CRES is the collection of professional knowledge which very often is missing, forgotten, or unrecorded by the expert. This is especially true when the expert uses the "rule of thumb" or "common sense" approach to judge a culvert. Therefore, questionnaires based on Table 7 should be carefully developed.

Also the CRES should be designed in such a way that when additional information is obtained one can delete, add or modify the knowledge base easily to accommodate new information. When new rules are added, one should note the consistency of the rules.

3.6.2 Explanations

Without the explanations, the CRES will be useless. The user will not know what kind of information is needed when using the micro-computer. For instance, when the CRES needs to know the concrete strength, but it does not specify the unit, great confusion will be created for the user. So, a step-by-step procedure for using the micro-computer and the explanation of each input are needed to clarify any doubt that may arise when using the
CRES. Thus, when the user does not understand a certain question, he/she should press the "help" key, and the explanation will be shown on the screen.

3.7 Computation Mechanism

The CRES is required to compute the regression equation which yields the quantitative rating. As mentioned before, the regression is obtained based on seven variables. But the final equation only uses four variables [10]; the equation is

\[
\text{RATE} = -0.5469 + 0.03155 \times \text{AGE} + 0.009898 \times \text{RISE} \\
+ 11.2483 / \text{PH} + 0.2377 \times \sqrt{\text{SLOPE}}
\]  \hspace{1cm} (1)

The quantitative rating based on the above equation. The program is written for easy change in case the user has input the wrong values.
CHAPTER IV
METHODOLOGY

4.1 Introduction

The inspector is responsible for physically inspecting the concrete culvert as well as collecting other necessary data so that the CRES can be used. The computer will then ask a series of questions. When all the conditions are met for a rule, it will display the particular production rule. More questions will be asked if there are additional conclusions to be reached.

As mentioned earlier, the qualitative rating, the quantitative rating, the inspector's rating, and the supervisor weighting of the above ratings are needed before the final concrete rating can be reached.

4.1.1 Qualitative rating

The qualitative rating is based on ODOT's concrete culvert pipe evaluation scale which is shown in Table 5. The culvert inspector needs to enter the answer for each parameter so that the CRES can determine the qualitative rating (the parameters were shown in Table 7.)
The CRES will use the expert opinions to determine a rating. Notice that the evaluation scale in Table 5 did not cover any in-between rating (e.g. a rating between good and fair). However, the CRES has the capability to do so. Therefore, the rating is more accurate than the usual inspection procedure since it covers all the possible ratings. There are nine possible ratings for the qualitative procedure, which is shown in Table 10.

### Table 10 Possible Qualitative Ratings for CRES

<table>
<thead>
<tr>
<th>Rating (1)</th>
<th>Linguistic Value (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Undecided</td>
</tr>
<tr>
<td>1</td>
<td>Excellent</td>
</tr>
<tr>
<td>1.5</td>
<td>Between Excellent and Very Good</td>
</tr>
<tr>
<td>2</td>
<td>Very Good</td>
</tr>
<tr>
<td>2.5</td>
<td>Between Very Good and Good</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
</tr>
<tr>
<td>3.5</td>
<td>Between Good and Fair</td>
</tr>
<tr>
<td>4</td>
<td>Fair</td>
</tr>
<tr>
<td>5</td>
<td>Poor</td>
</tr>
</tbody>
</table>

4.1.2 Quantitative rating

The quantitative rating included in this study includes four variables: the water PH, flow velocity (FVEL), rise, and age. This comes from a regression model reported by Hadipriono [10] using 399 observations of ratings and the seven independent variables in Table 11. The regression method is discussed in [10,21,22]. The
response variable of the regression equation is a predicted rating from 1 to 5 as shown in Table 12.

Table 11 Variables in Dataset [10]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Range</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>Age of pipes</td>
<td>1 - 45</td>
<td>years</td>
</tr>
<tr>
<td>Rise</td>
<td>Rise or diameter</td>
<td>24 - 108</td>
<td>inches</td>
</tr>
<tr>
<td>Fdepth</td>
<td>Flow depth</td>
<td>0 - 26</td>
<td>inches</td>
</tr>
<tr>
<td>Fvel</td>
<td>Flow velocity</td>
<td>-</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Sdepth</td>
<td>Sediment depth</td>
<td>0 - 60</td>
<td>inches</td>
</tr>
<tr>
<td>Slope</td>
<td>Slope of pipes</td>
<td>0.01 - 58</td>
<td>%</td>
</tr>
<tr>
<td>PH</td>
<td>PH of water inside pipes</td>
<td>2.4 - 9</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 12 Possible Quantitative, Inspector Rating and the Range

<table>
<thead>
<tr>
<th>Range</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00000 - 1.33333</td>
<td>Excellent</td>
</tr>
<tr>
<td>1.33333 - 1.66667</td>
<td>Between excellent and very good</td>
</tr>
<tr>
<td>1.66667 - 2.33333</td>
<td>Very good</td>
</tr>
<tr>
<td>2.33333 - 2.66667</td>
<td>Between very good and good</td>
</tr>
<tr>
<td>2.66667 - 3.33333</td>
<td>Good</td>
</tr>
<tr>
<td>3.33333 - 3.66667</td>
<td>Between good and fair</td>
</tr>
<tr>
<td>3.66667 - 4.33333</td>
<td>Fair</td>
</tr>
<tr>
<td>4.33333 - 5.00000</td>
<td>Poor</td>
</tr>
</tbody>
</table>

4.1.3 Inspector's rating

The inspector does not participate in rating the concrete culvert pipe except in the collection data. However, when an inspector goes to the field to collect data, he/she has an opinion about the culvert. This
information is very valuable to the CRES because the inspector is the only person who has seen the culvert. The inspector knows the appearance of the culvert better than anyone else.

The rating given by the inspector should be any number between 1 to 5, where 1 indicates the culvert is in excellent condition and 5 indicates a poor condition. Table 12 also shows the range for inspector ratings.

4.1.4 Supervisor weighting

The supervisor is the one who knows well the qualitative, quantitative and inspector rating performance; hence, he/she will use a weighting factor to correct the ratings.

The qualitative rating depends on the precision of the ODOT evaluation scale. If the evaluation scale has given a precise description of each rating, the qualitative rating will be more accurate.

The quantitative rating is the regression analysis method, which produces a regression equation based on seven independent variables and one dependent variable (concrete rating). This equation depends on the variables and the data. If more appropriate variables and data are included in the analysis, a better regression equation can
be obtained. The regression equation used here has an R-square value of 0.39, which might be improved with more data.

How well an inspector rates a concrete pipe depends on the experience and the training he/she has. Some inspectors can give a more accurate rating than others. Usually, the supervisor knows his/her inspector's performance.

The weighting is the belief of the supervisor's ability to rate the pipe accurately. The weighting is between 0 to 10. For example, an experienced inspector will have a high weighting. On the other hand, if the regression equation is not a good predictive model, the weighting on the quantitative rating will be low.
4.2 Introduction to EXSYS [6]

Exsys is an expert system shell, which primarily consists of an empty knowledge base and the inference mechanism. The Exsys derives conclusions by using the production rules. There are three ways of representing the probability in Exsys. There are 1) 0 or 1 system, 2) 0 - 10 system and 3) 0 - 100 system. Only one kind of representation can be used.

The 0 or 1 system is the most simple representation. This procedure does not really assign probability. A value of 0 means FALSE and 1 means TRUE.

The second system uses integer values from 0 to 10. A 0 means absolutely false (0/10), and 10 means absolutely true (10/10). Values 1-9 represent the degree of certainty with the denominator of 10. If there are only a few rules with probability, the final value will be the average of the rules provided there are no 0 or 10. For instance, if the rules with probabilities of 2/10, 9/10, 7/10 and 6/10, then the final probability will be the average of four rules, which is 6/10. When the 0 or 10 are used, the final probability will be locked at the first 0 or 10 will prevail. For example, if three values of 0/10, 9/10 and 10/10 are used, the final probability is 0/10. But if 10/10, 9/10 and 0/10 are used, the final probability is 10/10. Therefore, the order of the rules are very important in determining the final probability.
The third system uses integer values from 0 to 100. A 0 means absolutely false, and a 100 means absolutely true. Values of 1-99 represent the degree of certainty with the denominator of 100. Unlike the second system, a value of 0 or 100 does not lock the final probability value. The final probability of this system is computed using either the average, dependent or independent method.

4.2.1 Rules

The rules in the Exsys are represented like the production rules, which consist of many IF - THEN statements. Also, the AND, OR and NOT can also be used. For instance,

\[
\text{IF} : \quad \text{Condition 1} \\
\text{and} \quad \text{Condition 2} \\
\text{or} \quad \text{Condition 3} \\
\text{not} \quad \text{Condition 4} \\
\text{THEN} \\
\text{Conclusions}
\]

One can also input the reference and note for each rule.

4.2.2 Qualifier

The condition is made up of a qualifier with one or more values. For instance,

THE CONDITION OF THE CULVERT IS

1. EXCELLENT
2. VERY GOOD
"The condition of the culvert is " is the qualifier whose value is either "excellent" or "very good."

4.2.3 Choices

The choices are the possible solutions to the problem. There can be more than one choice in a rule. Also, the probability of the choice depends on a system like 0 or 1.

4.3 Procedure for Creating a New Knowledge Base with EXSYS

1) Insert the DOS (disk operating disk) into A drive and a blank formatted disk into B drive for data storage.
2) Turn the computer on.

The following message will appear on the screen:

Current date is Tue 1-01-1980
Enter new date:

Please type the new date and press RETURN. Another message will follow:

Current date is Tue 1-01-1980
Enter new date: 1-19-87 <RETURN>
Current time is 0:00:22.02
Enter new time:

After the new time is entered, press RETURN. The A > will be shown on the screen.

Current date is Tue 1-01-1980
Enter new date: 1-19-87
Current time is 0:00:22.02
Enter new time: 10:50 <RETURN>
3) Replace the DOS with the EDITXS disk. On the A > prompt sign, type EDITXS and press RETURN.

A> EDITXS <RETURN>

For monitors without color, NOCOLOR should be added after EDITXS. The following figures show step-by-step how to create a new knowledge base. For clarification, user input is shown with underline.
Screen 1.

EDITXS
Expert System Rule Editor
(c) copyright 1983,84,85 Dustin Huntington
Ver. 2.3.4
Expert System file name: B:CRES

Screen 2.

File B:CRES.TXT is not on the disk.
Do you wish to start a new file? (Y/N): Y

Screen 3.

Subject of knowledge base:
IMPROVEMENT OF CONCRETE PIPE CULVERT RATINGS USING EXPERT SYSTEM.

Screen 4.

Author: Barry K.H. Wong
Screen 5.

How do you wish the data on the available choices structured:

1 - Simple yes or no

2 - A range of 0-10 where 0 indicates absolutely not and 10 indicates absolutely certain. 1-9 indicate degrees of certainty.

3 - A range of 0-100 indicating the degree of certainty

Input number of selection or <H> for help: 2

Screen 6.

Input the text you wish to use to explain how to run this file. This text will be displayed at the start of EXSYS

This program is limited to only concrete pipe culverts. The user has to input the necessary information so that the Expert System can derive the final concrete rating.
Input the text you wish to use at the end of the EXSYS run. This will be displayed when the rules are done but before the choices and their calculated values are displayed.

The final concrete rating is obtained from:

1) Qualitative Rating,
2) Quantitative Rating,
3) Inspector Rating, and
4) Supervisor Weighting.

Do you wish the user running this expert system to have the rules displayed as the default condition. (The user will have the option of overriding this option)
(Y/N) (Default = N): N

Do you wish to have an external program called at the start of a run to pass data back for multiple variables or qualifiers. (If external programs are to be used only to get data for single variables select <N> (Y/N) (default=N): N
Input the choices to select among. Input just <ENTER> when done. Additional choices can be added later.
1. THE CONDITION OF THE CULVERT IS EXCELLENT

The function that checks new rules against the previous ones does not check the validity of mathematical formulas. If you predominantly use formulas it may be more convenient to switch this option off.

Do you wish new rules checked against the previous rules? Y/N (default = Y): Y

Do you wish to change the text in the:

Subject line .............<S>
Author ...................<A>
Beginning text ..........<B>
Ending text .............<E>
Variables .................<V>
External program ......<P>

No changes ..............<ENTER>

Your selection: <ENTER>

After ENTER is hit, the main screen for the editor will appear. If another ENTER is hit, user is ready to input the rules. Type N to input a new qualifier or M for math condition.
4.6 Running the EXSYS

Two problems were chosen to demonstrate the use of the expert system. A step-by-step guide for using the EXSYS is shown in Appendix A and B. A regression equation rating is from 1 to 5 which has been separated into sub-parts to accommodate the in-between rating. The sub-part's range and the possible rating is shown in Table 12.

Problem 1.

Mr. Smith, the inspector, has provided the following information.

a) Qualitative rating

1) CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
2) DISCOLORATION BUT NO LOSS, CORROSION OR SOFTENING IS FALSE
3) SLIGHT LOSS OF MORTAR IS TRUE
4) AGGREGATE EXPOSED IS TRUE
5) MODERATE LOSS OF MORTAR IS FALSE
6) MODERATE LOSS OF AGGREGATE IS FALSE
7) SLIGHT SOFTENING OF CONCRETE IS FALSE
8) SIGNIFICANT LOSS OF MORTAR IS FALSE
9) SIGNIFICANT LOSS OF AGGREGATE IS FALSE
10) COMPLETE LOSS OF INVERT IS FALSE
11) CONCRETE IN SOFTENED CONDITION IS FALSE
b) Field data  
Age = 15 years 
PH = 7.2 
Slope = 1.0 % 
Rise = 54 inches  
c) Inspector rating = 2  
d) Supervisor weighting 
Qualitative rating = 8 / 10 
Quantitative rating = 5 / 10 
Inspector rating on Mr. Smith = 8 / 10 

Given the above information, the EXSYS can be used to demonstrate how the CRES works. Again, when the computer is turned on, the A> will appear. Then type

A> EXSYS

The figures in Appendix A and B show step-by-step how to run the EXSYS, which is self explanatory. Also, the user input is shown with underline.

From Appendix A, the quantitative rating is Very Good, the qualitative rating is Good, the inspector rating is Very Good, and the final concrete rating is between Very Good and Good.

Problem 2.

The following information is provided by the inspector.

a) Qualitative rating 
1) CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE 
2) DISCOLORATION BUT NO LOSS, CORROSION OR SOFTENING IS FALSE 
3) SLIGHT LOSS OF MORTAR IS FALSE 
4) AGGREGATE EXPOSED IS TRUE 
5) MODERATE LOSS OF MORTAR IS TRUE 
6) MODERATE LOSS OF AGGREGATE IS TRUE
7) SLIGHT SOFTENING OF CONCRETE IS TRUE
8) SIGNIFICANT LOSS OF MORTAR IS FALSE
9) SIGNIFICANT LOSS OF AGGREGATE IS FALSE
10) COMPLETE LOSS OF INVERT IS FALSE
11) CONCRETE IN SOFTENED CONDITION IS FALSE

b) Field data
Age = 45 years
PH = 8
Slope = 0.01 %
Rise = 42 inches
c) Inspector rating = 2
d) Supervisor weighting
Qualitative rating = 8 / 10
Quantitative rating = 5 / 10
Inspector rating on Mr. Smith = 8 / 10

Based on the information from problem 2, the quantitative rating is between Very Good and Good, the qualitative rating is Fair, the inspector rating is between Excellent and Very Good, and the final concrete rating is Good.
CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This thesis introduces a technique for developing an expert system to improve the rating of concrete culverts (CRES). The information from the CRES is used to predict when a concrete culvert pipe needs repair or replacement. In turn, maintenance can be done on time to protect the public safety and to reduce the cost of repairing or replacing the culvert.

The sample model using the EXSYS has shown that the CRES is feasible, effective, and easy to use. The importance of improving the culvert rating and the technique of developing the CRES has also been discussed. The CRES can be used by anyone, provided the user has the inspector's observations, field data, inspector judgment, and the supervisor weighting on the above ratings. But, the final outcome should be analyzed by an expert. This is cost effective since the user does not have to be the supervisor, inspector, or expert.

The regression equation used in this thesis has an R-square value of 0.39 which is rather low. More data must be collected to improve the prediction accuracy.
Further study can be performed to improve the rules for both the qualitative and quantitative approaches. More specifically, the following topics are recommended to improve culvert ratings.

1. **Improved evaluation scale.**

   The concrete rating depends on the evaluation scale which should be improved so that the inspectors can easily distinguish different kinds of deterioration. The evaluation scale should break down into more precise descriptions in order to avoid confusion.

2. **Inspection procedure.**

   Inspectors should be well trained to differentiate the different types of deterioration. The author suggests that the Department of Transportation should develop a set of photographs to help inspectors distinguish the various kinds of failures.

3. **Collection of field data.**

   There were only seven independent variables with 399 observations considered in the regression analysis. Many of the observations were removed due to missing values. The regression equation can be improved if there are more variables and observations.
4. **Design criteria.**

Design criteria, such as concrete strength and cement type should be stored in the computer for future use.

5. **Expansion of CRES.**

The CRES can be expanded to include steel and aluminium. Rules will be needed to identify the kind of culvert being analyzed. Also, structure failure measurements should be included in the system. It would then be possible to develop an evaluation scale based on, say, the crack size of the concrete.
REFERENCES


6. EXSYS. "Expert System Development Package"


APPENDIX - A

PROBLEM 1
Screen 1.

EXSYS
Expert System Rule Editor
(c) copyright 1983,84 Dustin Huntington
Ver. 2.3.1

Expert System file name: B:CRES

Screen 2.

Do you wish instruction on running the program (Y/N): N

Screen 3.

Recover previously saved position Y/N (Default=N): N

Screen 4.

Do you wish to have the rules displayed as they are used (Y/N) (Default = Y): Y
Screen 5.

Improvement of Concrete Culvert Rating Using Expert System.

by: Barry K.H. Wong

Press any key to start:

Screen 6.

This program is limited to only concrete pipe culverts. The user has to input the necessary information so that the expert system can produce the final concrete rating.

Press any key to start:

Screen 7.

TURBO Pascal system Version 3.01A PC-DOS

Copyright (C) 1983,84,85 BORLAND Inc.

b/w display 80x25

include error message (Y/N)?Y
Screen 8.

Logged drive: A
Active directory: \\n
Work file:
Main file:

Edit       Compile   Run   Save
Dir        Quit      compiler Options

Text: 0 bytes
Free: 63485 bytes

> R

Work file name: B:RATE

Screen 9.

THE INPUT MUST BE IN THE FOLLOWING UNIT AND RANGE:

=============================================  
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>UNIT</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>AGE</td>
<td>YEARS</td>
<td>1 - 45</td>
</tr>
<tr>
<td>RISE</td>
<td>INCHES</td>
<td>24 - 108</td>
</tr>
<tr>
<td>SLOPE</td>
<td>%</td>
<td>0.01 - 58</td>
</tr>
<tr>
<td>PH</td>
<td>-</td>
<td>2.4 - 9</td>
</tr>
</tbody>
</table>

=============================================  

PLEASE INPUT THE AGE OF THE CONCRETE CULVERT = 15
PLEASE INPUT THE RISE OF THE CONCRETE CULVERT = 54
PLEASE INPUT THE SLOPE OF THE CONCRETE CULVERT = 1
PLEASE INPUT THE PH OF THE CONCRETE CULVERT = 7.2
THE INPUT FOR THE QUANTITATIVE RATING IS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ASSIGN VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) AGE</td>
<td>15 YEARS</td>
</tr>
<tr>
<td>2) PH</td>
<td>7.20</td>
</tr>
<tr>
<td>3) SLOPE</td>
<td>1.00 %</td>
</tr>
<tr>
<td>4) RISE</td>
<td>54 INCHES</td>
</tr>
</tbody>
</table>

THE QUANTITATIVE RATING IS = 2.26

PRESS ANY KEY TO CONTINUE............
THE BASIC QUANTITATIVE RATING

RATING (1)  LINGUISTIC VALUE (2)

1.00000 - 1.33333  Excellent
1.33333 - 1.66667  Between excellent and very good
1.66667 - 2.33333  Very good
2.33333 - 2.66667  Between very good and good
2.66667 - 3.33333  Good
3.33333 - 3.66667  Between good and fair
3.66667 - 4.33333  Fair
4.33333 - 5.0     Poor

PLEASE MATCH THE CALCULATED RATING TO THE ABOVE TABLE TO OBTAIN THE LINGUISTIC VALUE

THE CALCULATED RATING IS = 2.26

PRESS ANY KEY TO CONTINUE....

CONDITION OF CONCRETE AS CONSTRUCTED IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
Screen 13.

DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 14.

SLIGHT LOSS OF MORTAR IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 15.

AGGREGATE EXPOSED IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
Screen 16.

MODERATE LOSS OF MORTAR IS

1  TRUE
2  FALSE

2

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 17.

MODERATE LOSS OF AGGREGATE IS

1  TRUE
2  FALSE

2

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 18.

SLIGHT SOFTENING OF CONCRETE IS

1  TRUE
2  FALSE

2

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
SIGNIFICANT LOSS OF MORTAR IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help.

SIGNIFICANT LOSS OF AGGREGATE IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help.

COMPLETE LOSS OF INVERT IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help.
CONCRETE IN SOFTENED CONDITION IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 23.

RULE NUMBER: 11
IF:
1) CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and 2) DISCOLORATION BUT NO LOSS, CORROSION OR
SOFTENING IS FALSE
and 3) SLIGHT LOSS OF MORTAR IS TRUE
and 4) AGGREGATE EXPOSED IS TRUE
and 5) MODERATE LOSS OF MORTAR IS FALSE
and 6) MODERATE LOSS OF AGGREGATE IS FALSE
and 7) SLIGHT SOFTENING OF CONCRETE IS FALSE
and 8) SIGNIFICANT LOSS OF MORTAR IS FALSE
and 9) SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and 10) COMPLETE LOSS OF INVERT IS FALSE
and 11) CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:
THE QUALITATIVE RATING (QLR) IS GOOD

Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:
RULE NUMBER: 45
IF:
   (1) THE QUALITATIVE RATING (QLR) IS GOOD
THEN:
   [OBS] IS GIVEN THE VALUE 3

Input IF line number for info on how it was derived <H> for help or <ENTER> to continue:

RULE NUMBER: 57
IF:
   (1) [OBS] <= 5
THEN:
   [FINAL] IS GIVEN THE VALUE
   10*([ST1]+[ST2]+[ST3])/[WTRATE]+[WTOBS]+[WTINSP])

Input IF line number for info on how it was derived <H> for help or <ENTER> to continue:
RULE NUMBER: 56

IF:

(1) 0 < [OBS]
(2) [OBS] \leq 5

THEN:

[ST1] IS GIVEN THE VALUE [OBS]*[WTOBS]/10

Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:

Screen 27.

The value of the variable WTOBS is needed

Please input the value of THE WEIGHT OF THE QUALITATIVE RATING (0-10) OR ENTER "WHY" FOR DESCRIPTION

Value: 8

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit
RULE NUMBER: 54

IF:

(1) \[ \text{OBS} \leq 5 \]

THEN:

\[ \text{ST2} \text{ is given the value } \frac{\text{RATE} \times \text{WTRATE}}{10} \]

Input IF line number for info on how it was derived

<H> for help or <ENTER> to continue:

Screen 29.

The value of the variable WTRATE is needed

Please input the value of THE WEIGHT OF THE QUANTITATIVE RATING (0-10) OR ENTER "WHY" FOR DESCRIPTION

Value: 5

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit
RULE NUMBER: 53
IF:

(1) [OBS] <= 5

THEN:

[ST3] IS GIVEN THE VALUE [INSP]*[WTINSP]/10

Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:

Screen 31.

The value of the variable INSP is needed

Please input the value of THE INSPECTOR RATING (0-5)
OR ENTER "WHY" FOR DESCRIPTION

Value: 2

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit
Screen 32.

RULE NUMBER: 61
IF:

(1) 2.33333 < [FINAL]
and (2) [FINAL] <= 2.66667

THEN:
THE FINAL CONCRETE RATING IS BETWEEN VERY GOOD AND GOOD - Probability - Probability = 10/10

The final concrete rating is obtained from
1) Qualitative Rating,
2) Quantitative Rating,
3) Inspector Rating, and
4) Supervisor Weighting.

Press any key to display results:

Screen 34.

1. THE FINAL CONCRETE RATING IS BETWEEN VERY GOOD AND GOOD - Probability :10/10
2. THE QUANTITATIVE RATING = 2.260898
3. THE INSPECTOR RATING (0-5) = 2.0000
4. THE QUALITATIVE RATING = 3.0000

All choices <A>, value>0 <G>, Print <P>, Change and Rerun <C>, Quit/store <Q>, rules used <line number>, Help<H>, Done<D>:
APPENDIX B

PROBLEM 2
Screen 1.

The input must be in the following unit and range:

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>UNIT</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>YEARS</td>
<td>1 - 45</td>
</tr>
<tr>
<td>RISE</td>
<td>INCHES</td>
<td>24 - 108</td>
</tr>
<tr>
<td>SLOPE</td>
<td>%</td>
<td>0.01 - 58</td>
</tr>
<tr>
<td>PH</td>
<td>-</td>
<td>2.4 - 9</td>
</tr>
</tbody>
</table>

Please input the age of the concrete culvert = 45
Please input the rise of the concrete culvert = 42
Please input the slope of the concrete culvert = 0.01
Please input the pH of the concrete culvert = 8.0
Screen 2.

THE INPUT FOR THE QUANTITATIVE RATING IS

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ASSIGN VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) AGE</td>
<td>45 YEARS</td>
</tr>
<tr>
<td>2) PH</td>
<td>8.00</td>
</tr>
<tr>
<td>3) SLOPE</td>
<td>0.01 %</td>
</tr>
<tr>
<td>4) RISE</td>
<td>42 INCHES</td>
</tr>
</tbody>
</table>

THE QUANTITATIVE RATING IS = 2.72

PRESS ANY KEY TO CONTINUE.............
### THE BASIC QUANTITATIVE RATING

<table>
<thead>
<tr>
<th>RATING (1)</th>
<th>LINGUISTIC VALUE (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00000 - 1.33333</td>
<td>Excellent</td>
</tr>
<tr>
<td>1.33333 - 1.66667</td>
<td>Between excellent and very good</td>
</tr>
<tr>
<td>1.66667 - 2.33333</td>
<td>Very good</td>
</tr>
<tr>
<td>2.33333 - 2.66667</td>
<td>Between very good and good</td>
</tr>
<tr>
<td>2.66667 - 3.33333</td>
<td>Good</td>
</tr>
<tr>
<td>3.33333 - 3.66667</td>
<td>Between good and fair</td>
</tr>
<tr>
<td>3.66667 - 4.33333</td>
<td>Fair</td>
</tr>
<tr>
<td>4.33333 - 5.0</td>
<td>Poor</td>
</tr>
</tbody>
</table>

---

**PLEASE MATCH THE CALCULATED RATING TO THE ABOVE TABLE TO OBTAIN THE LINGUISTIC VALUE**

**THE CALCULATED RATING IS = 2.72**

PRESS ANY KEY TO CONTINUE.....

---

### Screen 4.

**CONDITION OF CONCRETE AS CONSTRUCTED IS**

1. TRUE
2. FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
Screen 5.

DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS
1 TRUE
2 FALSE

2

Enter number(s) of appropriate value(s), WHY
for information on the rule being applied,
QUIT to store data and exit or <H> for help

Screen 6.

SLIGHT LOSS OF MORTAR IS
1 TRUE
2 FALSE

2

Enter number(s) of appropriate value(s), WHY
for information on the rule being applied,
QUIT to store data and exit or <H> for help

Screen 7.

AGGREGATE EXPOSED IS
1 TRUE
2 FALSE

1

Enter number(s) of appropriate value(s), WHY
for information on the rule being applied,
QUIT to store data and exit or <H> for help
Screen 8.

MODERATE LOSS OF MORTAR IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 9.

MODERATE LOSS OF AGGREGATE IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 10.

SLIGHT SOFTENING OF CONCRETE IS
1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
Screen 11.

SIGNIFICANT LOSS OF MORTAR IS
1 TRUE
2 FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 12.

SIGNIFICANT LOSS OF AGGREGATE IS
1 TRUE
2 FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

Screen 13.

COMPLETE LOSS OF INVERT IS
1 TRUE
2 FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help
CONCRETE IN SOFTENED CONDITION IS

1  TRUE
2  FALSE

Enter number(s) of appropriate value(s), WHY for information on the rule being applied, QUIT to store data and exit or <H> for help

RULE NUMBER: 12
IF:

1) CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and 2) DISCOLORATION BUT NO LOSS, CORROSION OR SOFTENING IS FALSE
and 3) SLIGHT LOSS OF MORTAR IS FALSE
and 4) AGGREGATE EXPOSED IS TRUE
and 5) MODERATE LOSS OF MORTAR IS TRUE
and 6) MODERATE LOSS OF AGGREGATE IS TRUE
and 7) SLIGHT SOFTENING OF CONCRETE IS TRUE
and 8) SIGNIFICANT LOSS OF MORTAR IS FALSE
and 9) SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and 10) COMPLETE LOSS OF INVERT IS FALSE
and 11) CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS FAIR

Input IF line number for info on how it was derived <H> for help or <ENTER> to continue:
RULE NUMBER: 46
IF:
   (1) THE QUALITATIVE RATING (QLR) IS FAIR
THEN:
   [OBS] IS GIVEN THE VALUE 4

---------------------------------------------------------------------
Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:

RULE NUMBER: 57
IF:
   (1) [OBS] <= 5
THEN:
   [FINAL] IS GIVEN THE VALUE
   10*([ST1]+[ST2]+[ST3])/[WTRATE]+[WTOBS]+[WTINSP])

---------------------------------------------------------------------
Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:
RULE NUMBER: 56

IF:

(1) \( 0 < [\text{OBS}] \)
(2) \([\text{OBS}] \leq 5\)

THEN:

\([\text{ST1}] \text{ IS GIVEN THE VALUE } [\text{OBS}] * [\text{WTOBS}] / 10\)

Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:

Screen 19.

The value of the variable \text{WTOBS} is needed

Please input the value of THE WEIGHT OF THE QUALITATIVE RATING (0-10) OR ENTER "WHY" FOR DESCRIPTION

Value: 8

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit
RULE NUMBER: 54
IF:

(1) \[\text{OBS} \leq 5\]

THEN:

\[[\text{ST2}] \text{ IS GIVEN THE VALUE } \frac{\text{RATE} \times \text{WTRATE}}{10}\]

Input IF line number for info on how it was derived <H> for help or <ENTER> to continue:

Screen 21.

The value of the variable WTRATE is needed

Please input the value of THE WEIGHT OF THE QUANTITATIVE RATING (0-10) OR ENTER "WHY" FOR DESCRIPTION

Value: 5

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit.
Screen 22.

RULE NUMBER: 53
IF:

(1) [OBS] <= 5

THEN:

[ST3] IS GIVEN THE VALUE [INSP]*[WTINSP]/10

Input IF line number for info on how it was derived <H> for help or <ENTER> to continue:

Screen 23.

The value of the variable INSP is needed

Please input the value of THE INSPECTOR RATING (0-5) OR AFTER "WHY" FOR DESCRIPTION

Value: 2

Enter the value, WHY for information on why the program needs this information or QUIT to store the current data and exit
RULE NUMBER: 61
IF:

(1) \[2.66667 < [\text{FINAL}]\]
and (2) \([\text{FINAL}] \leq 3.33333\)

THEN:

THE FINAL CONCRETE RATING IS GOOD -
Probability - Probability = 10/10

Input IF line number for info on how it was derived
<H> for help or <ENTER> to continue:

The final concrete rating is obtained from

1) Qualitative Rating,
2) Quantitative Rating,
3) Inspector Rating, and
4) Supervisor Weighting.

Press any key to display results:

1. THE FINAL CONCRETE RATING IS GOOD - Probability :10/10
2. THE QUANTITATIVE RATING = 2.718518
3. THE INSPECTOR RATING (0-5) = 1.50000
4. THE QUALITATIVE RATING = 4.00000

All choices <A>, value>0 <G>, Print <P>, Change and Rerun <C>, Quit/store <Q>, rules used <line number>, Help<H>, Done<D>:
APPENDIX C

EXAMPLES
<table>
<thead>
<tr>
<th>AGE</th>
<th>8 YEARS</th>
<th>25 YEARS</th>
<th>19 YEARS</th>
<th>35 YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RISE</td>
<td>72 IN.</td>
<td>72 IN.</td>
<td>60 IN</td>
<td>42 IN</td>
</tr>
<tr>
<td>SLOPE</td>
<td>3 %</td>
<td>3 %</td>
<td>0.01 %</td>
<td>0.01 %</td>
</tr>
<tr>
<td>PH</td>
<td>4.5</td>
<td>5</td>
<td>6.9</td>
<td>8.5</td>
</tr>
<tr>
<td>WTOBS</td>
<td>9.5</td>
<td>8</td>
<td>8.3</td>
<td>8.9</td>
</tr>
<tr>
<td>WTRATE</td>
<td>7</td>
<td>6</td>
<td>4.5</td>
<td>7.5</td>
</tr>
<tr>
<td>WTINSP</td>
<td>8.5</td>
<td>8</td>
<td>9.0</td>
<td>8.5</td>
</tr>
<tr>
<td>CONDITION OF CONCRETE AS CONST.</td>
<td>T</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>DISC BUT NO LOSS, CORROSION OR SOFTENING</td>
<td>F</td>
<td>T</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>SLIGHT LOSS OF MORTAR</td>
<td>F</td>
<td>F</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>AGGREGATE IS EXPOSED</td>
<td>F</td>
<td>F</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>MODERATE LOSS OF MORTAR</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>MODERATE LOSS OF AGGREGATE</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>SLIGHT SOFTENING OF CONCRETE</td>
<td>F</td>
<td>F</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF MORTAR</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF AGGREGATE</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>COMPLETE LOSS OF INVERT</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>CONCRETE IN SOFTENED CONDITION</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>QUANTITATIVE RATING</td>
<td>GO (3.329)</td>
<td>GO &amp; FA (3.616)</td>
<td>VG (2.300)</td>
<td>VG (2.320)</td>
</tr>
<tr>
<td>QUALITATIVE RATING</td>
<td>EX (1)</td>
<td>VG (2)</td>
<td>GO &amp; FA (3.5)</td>
<td>PO (5)</td>
</tr>
<tr>
<td>INSPECTOR RATING</td>
<td>1.9</td>
<td>3.0</td>
<td>4.2</td>
<td>4.3</td>
</tr>
<tr>
<td>FINAL CONCRETE RATING</td>
<td>VG (1.958)</td>
<td>GO (2.804)</td>
<td>GO &amp; FA (3.541)</td>
<td>FA (3.953)</td>
</tr>
<tr>
<td>OTHERS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGE</td>
<td>20 Years</td>
<td>20 Years</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>RISE</td>
<td>60 In.</td>
<td>60 In.</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>SLOPE</td>
<td>2 %</td>
<td>2 %</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>PH</td>
<td>4.5</td>
<td>4.5</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>WTOBS</td>
<td>8</td>
<td>8</td>
<td>=</td>
<td>10</td>
</tr>
<tr>
<td>WTRATE</td>
<td>6</td>
<td>6</td>
<td>=</td>
<td>3</td>
</tr>
<tr>
<td>WTINSVP</td>
<td>7</td>
<td>7</td>
<td>=</td>
<td>7</td>
</tr>
<tr>
<td>CONDITION OF CONCRETE AS CONST.</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>DISC BUT NO LOSS, CORROSION OR SOFTENING</td>
<td>T</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>SLIGHT LOSS OF MORTAR</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>AGGREGATE IS EXPOSED</td>
<td>F</td>
<td>T</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>MODERATE LOSS OF MORTAR</td>
<td>F</td>
<td>T</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>MODERATE LOSS OF AGGREGATE</td>
<td>F</td>
<td>T</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>SLIGHT SOFTENING OF CONCRETE</td>
<td>F</td>
<td>T</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF MORTAR</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>SIGNIFICANT LOSS OF AGGREGATE</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>COMPLETE LOSS OF INVERT</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>CONCRETE IN SOFTENED CONDITION</td>
<td>F</td>
<td>F</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>QUANTITATIVE RATING</td>
<td>GO &amp; FA (3.51)</td>
<td>GO &amp; FA (3.51)</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>QUALITATIVE RATING</td>
<td>VG (2)</td>
<td>FA (4)</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>INSPECTOR RATING</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>FINAL CONCRETE RATING</td>
<td>GO (2.766)</td>
<td>GO &amp; FA (3.528)</td>
<td>GO (3.19)</td>
<td>GO (2.92)</td>
</tr>
</tbody>
</table>

= same previous input
APPENDIX  D

PASCAL PROGRAM
PROGRAM RATE;

VA
AGE,PH,SLOPE,RATE : REAL;
RISE,I : INTEGER;
INFILE : TEXT;

PROCEDURE QUESTION;
BEGIN
CLRSCR;
WRITELN('THE BASIC QUANTITATIVE RATING');
WRITELN('======================================');
WRITELN(' RANGE RATING');
WRITELN(' (1) (2)');
WRITELN('---------------------------------------');
WRITELN(' 1.00000 - 1.3333 EXCELLENT');
WRITELN(' 1.33333 - 1.6666 BETWEEN EXCELLENT AND
VERY GOOD');
WRITELN(' 1.66667 - 2.33333 VERY GOOD');
WRITELN(' 2.33333 - 2.66667 BETWEEN VERY GOOD AND
GOOD');
WRITELN(' 2.66667 - 3.33333 GOOD');
WRITELN(' 3.33333 - 3.66667 BETWEEN GOOD AND FAIR');
WRITELN(' 3.66667 - 4.33333 FAIR');
WRITELN(' 4.33333 - 5.00000 POOR');
WRITELN('======================================');
WRITELN('PLEASE MATCH THE CALCULATED RATING TO THE
 ABOVE TABLE');
WRITELN('TO OBTAIN THE SUBJECTIVE RATING');
WRITELN('THE CALCULATED RATING IS = ',RATE:4:2);
WRITELN('PRESS ANY KEY TO CONTINUE............');
REPEAT UNTIL KEYPRESSED
END;
PROCEDURE SHOW_INPUT;
BEGIN
CLRSCR;
WRITeln;
WRITeln('THE INPUT FOR THE QUANTITATIVE RATING IS');
WRITeln;
WRITeln('================================');
WRITeln('VARIABLE ASSIGN VALUE');
WRITeln(' (1) (2) ');
WRITeln;
WRITeln('1 AGE','AGE:4:0,'YEARS');
WRITeln;
WRITeln('2 PH','PH:4:2');
WRITeln;
WRITeln('3 SLOPE','SLOPE:4:2,'%');
WRITeln;
WRITeln('4 RISE','RISE:4,'INCHES');
WRITeln;
WRITeln('================================');
WRITeln;
WRITeln;
IF (RATE > 0) AND (RATE <= 5) THEN
WRITeln('THE QUANTITATIVE RATING IS','RATE:4:2');
WRITeln;
WRITeln('PRESS ANY KEY TO CONTINUE ......');
REPEAT UNTIL KEYPRESSED;
WRITeln;
WRITeln;
END;

PROCEDURE ASK_INPUT;
BEGIN
WRITE('PLEASE INPUT THE AGE OF THE CONCRETE CULVERT =');
READLN(AGE);
WRITE('PLEASE INPUT THE RISE OF THE CONCRETE CULVERT =');
READLN(RISE);
WRITE('PLEASE INPUT THE SLOPE OF THE CONCRETE CULVERT =');
READLN(SLOPE);
WRITE('PLEASE INPUT THE PH OF THE CONCRETE CULVERT =');
READLN(PH);
WRITeln;
WRITeln;
END;
PROCEDURE WARNING;
BEGIN
CLRSCR;
WRITELN('THE INPUT MUST BE IN THE FOLLOWING UNIT AND
RANGE: ');
WRITELN;

WRITELN('============================================');
WRITELN;
WRITELN('VARIABLE UNIT RANGE ');
WRITELN(' (1) (2) (3) ');
WRITELN('--------------------------------------------');
WRITELN('AGE YEARS 1 - 45 ');
WRITELN('RISE INCHES 24 - 108 ');
WRITELN('SLOPE % 0.01 - 58 ');
WRITELN('PH • 2.4 - 9 ');
WRITELN;

WRITELN('============================================');
WRITELN;
WRITELN;
WRITELN;
END;

BEGIN

REPEAT
WARNING;
ASK INPUT;
IF (2.4<=PH) AND (PH<=9) AND (0.01<=SLOPE) AND
(SLOPE<=58) AND (24<=RISE) AND (RISE<=108) AND
(1<=AGE) AND (AGE<=45) THEN
BEGIN
RATE := -0.546921 + 0.031553*AGE + 0.009898487*RISE
+11.24835/PH + 0.237735*SQRT(SLOPE);
WRITELN;
SHOW_INPUT;
END
ELSE
BEGIN
CLRSCR;
FOR I := 1 TO 50 DO
BEGIN
CLRSCR;
WRITELN('WARNING......................');
END;
WRITELN;
WRITELN('PLEASE ASSIGN THE VALUE WITHIN RANGE');
WRITELN;
WRITELN('PLEASE TRY AGAIN');
WRITELN;
WRITELN('PRESS ANY KEY TO CONTINUE......');
REPEAT UNTIL KEYPRESSED;
WRITELN;
WRITELN;
    RATE := -1;
    SHOW_INPUT;
END;
UNTIL (RATE >= 0) AND (RATE <= 5);
QUESTION;
ASSIGN(INFILE,'RETURN.PRN');
REWRITE(INFILE);
WRITELN(INFILE,'V1',RATE);
CLOSE(INFILE);
END.
APPENDIX E

EXSYS OUTPUT
Subject:  
Improvement of Concrete Culvert Rating Using Expert System.

Author:  
Barry K.H. Wong

Starting text:  
This program is limited to only concrete pipe culverts. The user has to input the necessary information so that the expert system can produce the final concrete rating.

Ending text:  
The final concrete rating is obtained from  
1) Qualitative Rating,  
2) Quantitative Rating,  
3) Inspector Rating, and  
4) Supervisor weighting.

Uses all applicable rules in data derivations.  
Calls the external file.
RULES:

----------------------------------------

RULE NUMBER: 1

IF:
   0 <= [RATE]
   and [RATE] <= 1.33333

THEN:
   THE QUANTITATIVE RATING (QNR) IS EXCELLENT

----------------------------------------

RULE NUMBER: 2

IF:
   1.33333 < [RATE]
   and [RATE] <= 1.66667

THEN:
   THE QUANTITATIVE RATING (QNR) IS BETWEEN EXCELLENT AND VERY GOOD

----------------------------------------

RULE NUMBER: 3

IF:
   1.66667 < [RATE]
   and [RATE] <= 2.33333

THEN:
   THE QUANTITATIVE RATING (QNR) IS VERY GOOD

----------------------------------------

RULE NUMBER: 4

IF:
   2.33333 < [RATE]
   and [RATE] <= 2.66667

THEN:
   THE QUANTITATIVE RATING (QNR) IS BETWEEN VERY GOOD AND GOOD

----------------------------------------
RULE NUMBER: 5
IF:
   2.66667 < [RATE]
   and [RATE] <= 3.3333
THEN:
   THE QUANTITATIVE RATING (QNR) IS GOOD

RULE NUMBER: 6
IF:
   3.3333 < [RATE]
   and [RATE] <= 3.66667
THEN:
   THE QUANTITATIVE RATING (QNR) IS BETWEEN GOOD AND FAIR

RULE NUMBER: 7
IF:
   3.66667 < [RATE]
   and [RATE] <= 4.3333
THEN:
   THE QUANTITATIVE RATING (QNR) IS FAIR

RULE NUMBER: 8
IF:
   4.33333 < [RATE]
   and [RATE] <= 5
THEN:
   THE QUANTITATIVE RATING (QNR) IS POOR
RULE NUMBER: 9

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS TRUE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS FALSE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS EXCELLENT

RULE NUMBER: 10

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS TRUE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS FALSE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS VERY GOOD
RULE NUMBER: 11

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS TRUE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS GOOD

RULE NUMBER: 12

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF AGGREGATE IS TRUE
and SLIGHT SOFTENING OF CONCRETE IS TRUE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS FAIR
RULE NUMBER: 13

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS TRUE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS FAIR

RULE NUMBER: 14

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS TRUE
and SIGNIFICANT LOSS OF AGGREGATE IS TRUE
and COMPLETE LOSS OF INVERT IS TRUE
and CONCRETE IN SOFTENED CONDITION IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS POOR
RULE NUMBER: 15

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS TRUE
and SIGNIFICANT LOSS OF AGGREGATE IS TRUE
and COMPLETE LOSS OF INVERT IS TRUE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS POOR

RULE NUMBER: 16

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS TRUE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS TRUE
and CONCRETE IN SOFTENED CONDITION IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS POOR
RULE NUMBER: 17

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS TRUE
and AGGREGATE EXPOSED IS FALSE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN VERY GOOD AND GOOD

RULE NUMBER: 18

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN GOOD AND FAIR
RULE NUMBER: 19

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS TRUE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS TRUE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN GOOD AND FAIR

RULE NUMBER: 20

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS TRUE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS TRUE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN GOOD AND FAIR
RULE NUMBER: 21

IF:

- CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
- DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
- SLIGHT LOSS OF MORTAR IS FALSE
- AGGREGATE EXPOSED IS TRUE
- MODERATE LOSS OF MORTAR IS TRUE
- MODERATE LOSS OF AGGREGATE IS FALSE
- SLIGHT SOFTENING OF CONCRETE IS TRUE
- SIGNIFICANT LOSS OF MORTAR IS FALSE
- SIGNIFICANT LOSS OF AGGREGATE IS TRUE
- COMPLETE LOSS OF INVERT IS FALSE
- CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR

----------------~-----------------------

RULE NUMBER: 22

IF:

- CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
- DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
- SLIGHT LOSS OF MORTAR IS FALSE
- AGGREGATE EXPOSED IS TRUE
- MODERATE LOSS OF MORTAR IS FALSE
- MODERATE LOSS OF AGGREGATE IS TRUE
- SLIGHT SOFTENING OF CONCRETE IS TRUE
- SIGNIFICANT LOSS OF MORTAR IS TRUE
- SIGNIFICANT LOSS OF AGGREGATE IS FALSE
- COMPLETE LOSS OF INVERT IS FALSE
- CONCRETE IN SOFTENED CONDITION IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR

----------------~-----------------------
RULE NUMBER: 23

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF AGGREGATE IS TRUE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR

RULE NUMBER: 24

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS FALSE
and MODERATE LOSS OF AGGREGATE IS TRUE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS FALSE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR
RULE NUMBER: 25

IF:

CONDITION OF CONCRETE AS CONSTRUCTED IS FALSE
and DISCOLORATION BUT NO LOSS, CORROSION, OR SOFTENING IS FALSE
and SLIGHT LOSS OF MORTAR IS FALSE
and AGGREGATE EXPOSED IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF AGGREGATE IS FALSE
and SLIGHT SOFTENING OF CONCRETE IS FALSE
and SIGNIFICANT LOSS OF MORTAR IS FALSE
and SIGNIFICANT LOSS OF AGGREGATE IS TRUE
and COMPLETE LOSS OF INVERT IS FALSE
and CONCRETE IN SOFTENED CONDITION IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR

RULE NUMBER: 26

IF:

SLIGHT LOSS OF MORTAR IS TRUE
and MODERATE LOSS OF MORTAR IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 27

IF:

SLIGHT LOSS OF MORTAR IS TRUE
and SIGNIFICANT LOSS OF MORTAR IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)
RULE NUMBER: 28

IF: 
   MODERATE LOSS OF MORTAR IS TRUE  
   and  SIGNIFICANT LOSS OF MORTAR IS TRUE

THEN: 
   THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 29

IF: 
   SLIGHT SOFTENING OF CONCRETE IS TRUE  
   and  CONCRETE IN SOFTENED CONDITION IS TRUE

THEN: 
   THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 30

IF: 
   MODERATE LOSS OF AGGREGATE IS TRUE  
   and  SIGNIFICANT LOSS OF AGGREGATE IS TRUE

THEN: 
   THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)
RULE NUMBER: 31

IF:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

and

THE QUALITATIVE RATING (QLR) IS EXCELLENT or VERY GOOD or GOOD or FAIR or POOR or BETWEEN VERY GOOD AND GOOD or BETWEEN GOOD AND FAIR or BETWEEN FAIR AND POOR

THEN:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 32

IF:

MODERATE LOSS OF AGGREGATE IS TRUE

and

MODERATE LOSS OF MORTAR IS FALSE

THEN:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 33

IF:

AGGREGATES IS EXPOSED IS FALSE

and

MODERATE LOSS OF AGGREGATE IS TRUE

THEN:

THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)
RULE NUMBER: 34

IF:
   AGGREGATES IS EXPOSED IS FALSE
   and SIGNIFICANT LOSS OF AGGREGATE IS TRUE

THEN:
   THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

RULE NUMBER: 35

IF:
   0 <= [INSP]
   and [INSP] <= 1.33333

THEN:
   THE INSPECTOR RATING IS EXCELLENT

RULE NUMBER: 36

IF:
   1.33333 < [INSP]
   and [INSP] <= 1.66667

THEN:
   THE INSPECTOR RATING IS BETWEEN EXCELLENT AND VERY GOOD

RULE NUMBER: 37

IF:
   1.66667 < [INSP]
   and [INSP] <= 2.33333

THEN:
   THE INSPECTOR RATING IS VERY GOOD
RULE NUMBER: 38

IF:

\[ 2.33333 < [\text{INSP}] \]
\[ \text{and} \quad [\text{INSP}] \leq 2.66667 \]

THEN:

THE INSPECTOR RATING IS BETWEEN VERY GOOD AND GOOD

RULE NUMBER: 39

IF:

\[ 2.66667 < [\text{INSP}] \]
\[ \text{and} \quad [\text{INSP}] \leq 3.33333 \]

THEN:

THE INSPECTOR RATING IS GOOD

RULE NUMBER: 40

IF:

\[ 3.33333 < [\text{INSP}] \]
\[ \text{and} \quad [\text{INSP}] \leq 3.66667 \]

THEN:

THE INSPECTOR RATING IS BETWEEN GOOD AND FAIR

RULE NUMBER: 41

IF:

\[ 3.66667 < [\text{INSP}] \]
\[ \text{and} \quad [\text{INSP}] \leq 4.33333 \]

THEN:

THE INSPECTOR RATING IS FAIR
RULE NUMBER: 42

IF:
   4.3333 < [INSP]
   and [INSP] <= 5

THEN:
   THE INSPECTOR RATING IS POOR

RULE NUMBER: 43

IF:
   THE QUALITATIVE RATING (QLR) IS EXCELLENT

THEN:
   [OBS] IS GIVEN THE VALUE 1

RULE NUMBER: 44

IF:
   THE QUALITATIVE RATING (QLR) IS VERY GOOD

THEN:
   [OBS] IS GIVEN THE VALUE 2

RULE NUMBER: 45

IF:
   THE QUALITATIVE RATING (QLR) IS GOOD

THEN:
   [OBS] IS GIVEN THE VALUE 3
RULE NUMBER: 46

IF:  
    THE QUALITATIVE RATING (QLR) IS FAIR  
THEN:  
    [OBS] IS GIVEN THE VALUE 4

RULE NUMBER: 47

IF:  
    THE QUALITATIVE RATING (QLR) IS POOR  
THEN:  
    [OBS] IS GIVEN THE VALUE 5

RULE NUMBER: 48

IF:  
    THE QUALITATIVE RATING (QLR) IS BETWEEN EXCELLENT AND VERY GOOD  
THEN:  
    [OBS] IS GIVEN THE VALUE 1.5

RULE NUMBER: 49

IF:  
    THE QUALITATIVE RATING (QLR) IS BETWEEN VERY GOOD AND GOOD  
THEN:  
    [OBS] IS GIVEN THE VALUE 2.5
RULE NUMBER: 50

IF:  
    THE QUALITATIVE RATING (QLR) IS BETWEEN GOOD AND FAIR

THEN:  
    [OBS] IS GIVEN THE VALUE 3.5

RULE NUMBER: 51

IF:  
    THE QUALITATIVE RATING (QLR) IS BETWEEN FAIR AND POOR

THEN:  
    [OBS] IS GIVEN THE VALUE 4.5

RULE NUMBER: 52

IF:  
    THE QUALITATIVE RATING (QLR) IS UNDECIDED (please check the input again)

THEN:  
    [OBS] IS GIVEN THE VALUE 0

RULE NUMBER: 53

IF:  
    [OBS] <= 5

THEN:  
    [ST3] IS GIVEN THE VALUE [WTINS] *[INS]/10
RULE NUMBER: 54

IF:

[OBS] <= 5

THEN:

[ST2] IS GIVEN THE VALUE \([WTRATE][RATE]/10\)

RULE NUMBER: 55

IF:

[OBS] = 0

THEN:

[WTOBS] IS GIVEN THE VALUE 0

and [ST1] IS GIVEN THE VALUE 0

RULE NUMBER: 56

IF:

0 < [OBS]

and [OBS] <= 5

THEN:

[ST1] IS GIVEN THE VALUE \([OBS][WTOBS]/10\)

RULE NUMBER: 57

IF:

[OBS] <= 5

THEN:

[FINAL] IS GIVEN THE VALUE

\[10\times(([ST1]+[ST2]+[ST3])\div([WTRATE]+[WTOBS]+[WTINSP]))\]
RULE NUMBER: 58

IF:

0 <= [FINAL]
and [FINAL] <= 1.33333

THEN:
THE FINAL CONCRETE CULVERT RATING IS EXCELLENT - Probability = 10/10

RULE NUMBER: 59

IF:

1.33333 < [FINAL]
and [FINAL] <= 1.66667

THEN:
THE FINAL CONCRETE RATING IS BETWEEN EXCELLENT AND VERY GOOD - Probability = 10/10

RULE NUMBER: 60

IF:

1.66667 < [FINAL]
and [FINAL] <= 2.33333

THEN:
THE FINAL CONCRETE RATING IS VERY GOOD - Probability = 10/10

RULE NUMBER: 61

IF:

2.33333 < [FINAL]
and [FINAL] <= 2.66667

THEN:
THE FINAL CONCRETE RATING IS BETWEEN VERY GOOD AND GOOD - Probability = 10/10
RULE NUMBER: 62

IF:
   2.66667 < [FINAL]
   and [FINAL] <= 3.33333

THEN:
   THE FINAL CONCRETE RATING IS GOOD - Probability = 10/10

RULE NUMBER: 63

IF:
   3.33333 < [FINAL]
   and [FINAL] <= 3.66667

THEN:
   THE FINAL CONCRETE RATING IS BETWEEN GOOD AND FAIR
   - Probability = 10/10

RULE NUMBER: 64

IF:
   3.66667 < [FINAL]
   and [FINAL] <= 4.33333

THEN:
   THE FINAL CONCRETE RATING IS FAIR - Probability = 10/10

RULE NUMBER: 65

IF:
   4.33333 < [FINAL]
   and [FINAL] <= 5.0

THEN:
   THE FINAL CONCRETE RATING IS POOR - Probability = 10/10
VARIABLES:

1 RATE
   THE QUANTITATIVE RATING
   Displayed at the end of a run with a value

2 INSPIRATORATING (0 - 5)
   THE INSPECTOR RATING
   Displayed at the end of a run with a value

3 OBS
   THE QUALITATIVE RATING
   Displayed at the end of a run with a value

4 ST1
   STEP 1

5 WTOBS
   THE WEIGHT OF THE QUALITATIVE RATING (0 - 10) OR ENTER
   "WHY" FOR DESCRIPTION

6 ST2
   STEP2

7 WTRATE
   THE WEIGHT OF THE QUANTITATIVE RATING (0 - 10) OR ENTER
   "WHY" FOR DESCRIPTION

8 ST3
   STEP3

9 WTINSPIRATORATING (0 - 10) OR ENTER
   "WHY" FOR DESCRIPTION

10 FINAL
   THE FINAL CONCRETE RATING