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Final Report, Vol. 2

THE DEVELOPMENT OF OPTIMAL
STRATEGIES FOR MAINTENANCE,
REHABILITATION AND REPLACEMENT
OF HIGHWAY BRIDGES, FINAL
REPORT VOL. 2: A SYSTEM FOR
BRIDGE STRUCTURAL CONDITION
ASSESSMENT

Ah-Beng Tee
Kumares C. Sinha

Mark D. Bowman

PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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FINAL REPORT

The Development of Optimal Strategies for Maintenance,
Rehabilitation and Replacement of Highway Bridges
Final Report Vol. 2: A System for Bridge Structural Condition Assessment

TO: Harold L. Michael, Director August 15, 1989
Joint Highway Research Project Revised October 5, 1990

FROM: Kumares C. Sinha, Research Engineer Project: C-36-73I
Joint Highway Research Project File: 3-4-10

Please find attached Volume II of the Final Report on the HPR Study entitled, "The Development of Optimal Strategies for Maintenance, Rehabilitation and Replacement of Highway Bridges, Final Report Vol. 2: A System for Bridge Structural Condition Assessment". Its authors are A.B. Tee, M.D. Bowman and K.C. Sinha, and the research work in this phase was conducted under the direction of Mark D. Bowman.

This report describes the present bridge inspection practices in Indiana and their shortcomings, documents the development and implementation of a bridge inspection system and defines a procedure for the combination of subjective rating information. To enhance the overall accuracy of bridge inspection data, a system is developed that allows fast retrieval and storage of bridge information, systematically combines local element condition assessments to yield global bridge rating, and performs remaining life prediction. The proposed bridge system is predicated upon the fact that imprecision is inherent in bridge condition assessment. Since the main source of imprecision in bridge inspection is due to vagueness rather than randomness, it can be best handled using fuzzy mathematics.

This volume of the Final Report is submitted for review and approval as partial fulfillment of the objectives of the research.

Respectfully Submitted,

K. C. Sinha
Research Engineer

KCS/cah

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FINAL REPORT

The Development of Optimal Strategies for Maintenance,
Rehabilitation and Replacement of Highway Bridges
Final Report Vol. 2: A System for Bridge Structural Condition Assessment

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16. Abstract <p>This report is the second of a six-volume final report presenting the findings of the research work that was undertaken to develop a framework for managing bridge maintenance, rehabilitation and replacement activities in Indiana. This volume presents a system that can assist bridge inspectors in the assessment of bridge structural conditions. The procedure used is based on fuzzy sets mathematics. A computer program is discussed that can be run by bridge inspectors on personal computers.</p> <p>The titles of all six volumes are listed below:</p> <p>Vol. 1. Elements of Indiana Bridge Management System</p> <p>Vol. 2. A System for Bridge Structural Condition Assessment</p> <p>Vol. 3. Bridge Traffic Safety Evaluation</p> <p>Vol. 4. Cost Analysis</p> <p>Vol. 5. Priority Ranking Method</p> <p>Vol. 6. Bridge Performance and Optimization</p>			
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CHAPTER 1

INTRODUCTION

1.1 General Remarks

Bridge structures of today reflect the engineering experience and research developments that have evolved over many centuries. An impressive amount of research has been conducted in the development of new technology and materials for the design and construction of new bridges during the last fifty years. Welding, high strength bolts, epoxy coated reinforcing bars and prestressed concrete are but a few of the recent technological advances [OECD 1976]. Much research effort has also been devoted to the development of new non-destructive testing techniques. High-resolution radar systems have proven to be a reliable tool for determining the condition of concrete decks [Hays et al. 1983]. Electrochemical measurement and chloride ion analysis are new techniques available for corrosion monitoring. Various nondestructive techniques that can be used for field detection of fatigue cracks in welded highway bridges include radiography, ultrasonic testing, dye penetrant, magnetic particle, eddy current, acoustic holography and infrared emission. Moreover, the application of cathodic protection to steel in concrete decks offers promise of controlling corrosion problems [Park 1984].

Nevertheless, these technological advances have not precluded a number of unfortunate and, in some instances, tragic bridge failures. One area that has not received the deserved research effort is in the bridge inspection and management area. After a bridge has been built, it must be kept in a serviceable state through regular inspection and maintenance. Research in this area has been limited, and much remains to be studied.

1.2 Historic Background

After the catastrophic failure of the 39-year old Silver Bridge spanning the Ohio River on December 15, 1967, which claimed 46 lives, the United States Congress established a National Bridge Inspection Program [FHWA 1970]. The collapse of the 25-year old I-95 Mianus River Bridge on June 28, 1983, which took 3 lives, raised fear in the public and professional sector about the safety of the Nation's bridges and it aroused national interest and awareness in the importance of bridge inspection and management research. The collapse of the Scholarie Creek Bridge on the New York Thruway on April 5, 1987, which killed 10 persons, renewed awareness that bridges are deteriorating at an alarming rate. A recent Federal Highway Administration (FHWA) survey reported that every two days, on the average, another bridge sags, buckles, or collapses and that one bridge out of every five in the United States is deficient and dangerous to use [White et al. 1981]. Bridge deterioration is now recognized as a national problem.

1.3 Bridge Deterioration - A National Problem

There are approximately 600,000 highway bridges in the United States, one-half of which were built before 1940 [Reilly 1984]. By the turn of this century, sixty-five percent of these bridges will be older than their typical 50-year design life. Furthermore, many of these bridges in service today were designed for less traffic, smaller vehicles, slower speeds, and lighter loads than current standards employed for highway bridge design. Even in newer bridges, deterioration caused by service conditions and deferred maintenance is a growing problem.

The FHWA classifies the Nation's bridges based on the National Bridge Inventory (NBI) data compiled by each State. These data are collected pri-

marily to assist FHWA and the Congress for evaluation of the overall condition of the Nation's bridges. Based on these data, the FHWA reported that nearly 40 percent of the Nation's existing bridges are functionally or structurally deficient and in need of rehabilitation or replacement [Reilly 1984]. More than 100,000 of these are judged to be structurally deficient because of deterioration or distress and another 100,000 are functionally obsolete or inadequate for current requirements.

According to the 1988 Indiana bridge inventory, there are approximately 17,658 bridges and culverts in Indiana. More than 5,290 of these are state-maintained bridges. Of these state-maintained bridges, 1,789 bridges are functionally obsolete or inadequate for current requirements, and another 472 bridges are judged to be structurally deficient because of deterioration or distress [IDOH 1988].

These statistics clearly indicate that many of the bridges in Indiana and in the Nation on the whole are in need of repair or replacement. Furthermore, the number of deficient bridges is expected to increase rapidly due to aging, heavier truck loads, increased truck traffic volumes, the use of de-icing chemicals, and deferred maintenance [Imbsen 1984]. Funding levels for bridge repairs, however, are limited. The 1982 Surface Transportation Assistance Act (STAA) authorized \$7.05 billion for the Highway Bridge Replacement and Rehabilitation Program (HBRRP) to improve bridges on public highways throughout the country. However, this amount is far short of the funds necessary for meeting the existing bridge rehabilitation and replacement needs which FHWA estimated in 1984 to be approximately \$50 billion.

The above figures present an alarming picture of the status of the Nation's bridge condition. It is clear that engineers and decision makers

will have to deal with a large number of deficient bridges for years to come. Many states including FHWA have turned to research to provide new answers. A systematic method to assess present and future needs of existing bridges would be useful to decision makers involved in deciding the most deserving bridges for improvement during a given period. One such rational and systematic approach is the bridge management system.

1.4 Bridge Management Systems

Many states have either upgraded and initiated the development of a comprehensive bridge management system to assist their decision makers in finding optimal strategies for maintaining, rehabilitating, and replacing bridges. Bridge condition assessment, priority establishment and selection of maintenance and rehabilitation strategies all fall within the framework of a bridge management system. States are encouraged to develop bridge ranking and project selection procedures based on the sufficiency ratings and other appropriate factors which reflect State needs and local input to insure a fair and equitable distribution of funds throughout the State.

In the past, the vast majority of bridge projects have been determined based on their individual merits with little consideration of their impact upon the whole network of bridges or upon future needs [Hudson et al. 1987]. With a bridge management system, bridge engineers can determine how to use the limited funds more effectively. For example, useful information which bridge managers can obtain from a bridge management system include:

- o If bridge funds were significantly decreased, which bridge activities should be cut before the bridge program would fail to meet societal needs.
- o At the end of each year, which bridges would be added to the list of deficient bridges.

As in all other engineering management systems, the quality of the results from a bridge management system depends on the quality of the input information. Since all functions and decisions of a bridge management system originate from the bridge inspection data base, the system output is only as good as the available data; high quality, detailed data yield the maximum effectiveness from the system [Hudson et al. 1987].

1.5 Statement of Problem

As mentioned earlier, the bridge inspection data is a key input information in a bridge management system. Consequently, the usefulness of any bridge evaluation and priority setting system relies heavily upon the quality of the field data provided by the bridge inspectors. The optimal solution in any system will not be obtained if the input data is less than accurate. Therefore, it should be emphasized that the quality of the bridge inspection data dictates the success or failure of a bridge management system.

The current practices of bridge condition assessment invariably suffer from shortcomings because of the following inherent characteristics:

1. The parameters in bridge inspection such as the importance of deterioration are not completely defined or cannot be precisely measured;
2. Personal judgment, bias and subjectiveness are often included but not systematically accounted for in the evaluation process.
3. There is a lack of guidelines establishing the relationship between the extent of deterioration and the assignment of rating values.

Clearly, the current bridge inspection procedure is confronted with problems of imprecision and uncertainty. If the purpose of bridge inspection is to prevent tragic bridge collapse, then the imprecision inherent in the condition information may be negligible. Bridges that are on the verge of collapse will usually show visible signs of distress, such as large deflec-

tions, large cracks, noisy vibrations, etc., and can often be detected without much difficulty. However, for bridge management purposes, this problem of imprecision must be addressed and taken into account in the decision making process. This is particularly true for the situation in Indiana where there are a large number of deficient but still serviceable bridges and any subtle changes in inspection rating may cause a bridge to be either repaired or ignored.

Although most of the bridge management systems which are currently being developed or upgraded acknowledge the importance of reliable, consistent and uniform inspection data, they have not attempted to address this issue directly. It is left as an area for future research. Quality control of inspection data that are determined on the basis of subjective judgment is not a simple task. One of the methods of verifying the accuracy and reliability of inspection data involves random reinspection of bridges.

1.6 Purpose and Scope

The main objective of the present research study is to develop an evaluation mechanism for bridge inspection information that will take into account the imprecision and uncertainty in the inspection parameters. It will be designed to filter the field inspection information of any inconsistencies before entering the bridge management system. Moreover, the evaluation method will utilize the inspectors' judgment and experience in the inspection process, and promote consistency in the bridge ratings by systematically combining the inspection information. This data enhancement mechanism can also be employed to verify the accuracy and reliability of inspection data.

The scope of the present research study includes the following major tasks:

1. Review and document ongoing or completed research regarding the structural aspects of bridge management systems, i.e. the condition assessment of bridges;
2. Review the current bridge condition assessment practices in the state of Indiana;
3. Develop the mathematical foundation and concepts of the new inspection evaluation scheme;
4. Develop the framework (set of questionnaires) which can be used to acquire the expert knowledge base;
5. Develop membership functions and formulation of fuzzy bridge inspection model;
6. Provide a working version of the evaluation model for bridge inspection data

1.7 Structure of the Report

In Chapter 2 the available literature on bridge inspection and management is reviewed. The available damage functions that can be adopted for the bridge inspection study are discussed. Approaches relevant for application and modification in the present work are identified. In Chapter 3, current practices for bridge condition evaluation are summarized. An introduction to the bridge reporting systems in Indiana is described. In Chapter 4 the bridge elements and their common defects are briefly discussed.

Chapter 5 introduces the fundamental concepts of fuzzy set theory and discusses the important concept of membership functions. In Chapter 6 the use of fuzzy logic methods for bridge condition assessment is described.

The material in Chapter 7 deals with the implementation of the proposed methodology for the evaluation of bridge inspection information. Numerical examples are provided to illustrate the evaluation method. In Chapter 8, an

overall set of conclusions and summary of the findings based on the research carried out is given.

The survey results are included in Appendix A. A copy of the questionnaire used in the present study is included in Appendix B. A sample copy of the Indiana field inspection form and the structural inventory and appraisal sheet is included in Appendix C. Flowcharts for the implementation of the bridge inspection system are shown in Appendix D. An user guide for the bridge inspection system is presented in Appendix E. The bridge inspection program listing is included in Appendix F.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 General Remarks

Bridges are generally designed to meet specific human and societal needs subjected to safety, serviceability and economic feasibility considerations. Because the real bridge structure is a complex system, it is frequently necessary for designers to utilize idealized mathematical models during the analysis and design phase. Such simplification generally introduces some approximations and uncertainties into the design. The idealized design is then transformed into reality during the construction phase with the introduction of more uncertainties associated with the quality of workmanship and materials, and environmental variations. Moreover, the completed bridge is subjected to loading conditions which usually differ from the values used for design. As a result, the performance and behavior of a bridge upon completion is usually different from analytical results of idealized mathematical models employed in the design phase.

Such discrepancies are acceptable because analytical results have hidden safety factors and are much more conservative than actual performances of the real system. Consequently, designers are generally certain that the completed bridge structure is safe and satisfactory for its intended purpose, but they rarely know the precise degree of safety of the bridge.

In this chapter, available methodologies for condition assessment of existing bridges are briefly reviewed. Special emphasis is placed on those methods that are appropriate for the present work. Nevertheless, it must be recognized that these methodologies, while useful for purposes of analysis,

do have practical limitations and shortcomings, and will be examined and discussed where appropriate.

2.2 Review of Existing Bridge Management Systems

In this section, a brief review of the available bridge management systems is presented; with emphasis on how the field inspection information is used in these systems.

Much research effort has been devoted to the study and development of bridge management methods by a number of states in recent years [Hyman and Hughes 1983; PennDot 1984; Shirole 1984; Shirole and Hill 1978a, 1978b; Weyers et al. 1984]. These bridge management systems generally contain the main features of the Federal Sufficiency Rating system; the federal criteria are modified to suit the needs of each state. In general, the bridge ranking and optimization process in these systems allocates points to various sufficiency or deficiency factors. These points are based on the perceived ratings of the deck, superstructure, substructure, predicted remaining life, and the general bridge characteristics such as geometry, traffic volume, location, etc.

Many states have decided to develop their own bridge management system instead of using the Federal sufficiency rating system because the Federal system has been found to be deficient. Specifically, it has been found that the sufficiency rating system does not place enough emphasis on the appropriate level of service in proportion to public need (FHWA 1987). In other words, the sufficiency rating scheme places little emphasis on volume of traffic, detour length, and level of service needed on various functional systems such as arterials, collectors, and local systems, and too much emphasis on such things as temporary structures.

The North Carolina Department of Transportation has developed a level-of-service system for bridge evaluation [Johnston and Zia 1984]. Realizing that the Federal Sufficiency Rating does not place adequate emphasis on level of service provided to the public, a procedure for evaluating bridges and producing priority ranking has been developed. Characteristics that are assumed to contribute to making a bridge safe, functional, and beneficial to the public include load bearing capacity, clear bridge deck width, and vertical roadway underclearance and overclearance.

The Pennsylvania bridge management system contains elements of the North Carolina Method and the Federal Sufficiency Rating scheme [PennDot 1984]. This system systematically evaluates the bridge deficiencies and associated costs, records maintenance and construction cost history, and yields a spectrum of information designed to enable cost-effective management of Pennsylvania bridges. Deficiency points are given to the superstructure, substructure, and deck condition, and the estimated remaining life.

Other states that have developed a bridge management system are Kansas and Maryland. Kansas has a total management system for both pavements and bridges. Maryland has a management system which is concerned with only two basic problems: the maintenance of bridge deck and the rehabilitation and replacement of structural members. It uses the Federal Sufficiency Rating in conjunction with its own Deck Sufficiency Rating to generate priority ranking of bridge replacement and rehabilitation projects.

The National Cooperative Highway Research Program (NCHRP) recently sponsored the development of a bridge management system [Hudson et al. 1987]. A significant feature of the NCHRP bridge management system is the way bridge condition is handled. Each of the major components of a bridge (deck, super-

structure, substructure) is decomposed into subcomponents. The superstructure, substructure and deck have 8, 9 and 7 subcomponents, respectively. Each element is rated using the standard 0 to 9 scale. The rating of each subcomponents is stored in the bridge management system data base.

One important conclusion that can be drawn from the review of these bridge management systems is that the bridge field inspection information forms the starting point for the development of a bridge management system. Obviously, the usefulness of the improvement strategies generated by these systems rely upon the quality of the bridge inspection information.

From the literature search, it is evident that one of the major shortcomings of the existing bridge management systems to-date is still their failure to account for the discrepancies and inconsistencies of the field inspection data systematically. The bridge inspection data were not verified for their accuracy and reliability. Using these data without checking for reliability or taking into account the inherent bridge inspection discrepancies may not be commensurate with the accuracy desired by a rigorous bridge management system.

2.3 Modeling Techniques

2.3.1 Problem Reduction Approach

Bridge inspection is generally a complex assignment involving the use of various evaluation techniques required to assess the physical condition of a bridge. The difficulty of this assignment is further compounded by the fact that there are many different bridge types; each has many different components and subcomponents. Thus, an efficient way to handle this problem is to decompose it into simpler problems, which are further decomposed into even

simpler sub-problems. Such an approach allows a complex problem to be described hierarchically, and thus is particularly useful in applications involving knowledge manipulations such as in bridge inspection.

Using this approach, a complex bridge structure can be decomposed into three major components: deck, superstructure, and substructure. Each component can be further divided into simpler subcomponents. The evaluation of each subcomponent is much simpler to achieve; and can be obtained with greater consistency and accuracy. The condition of a major component is then inferred from the condition ratings of the simpler subcomponents. Such inference process can be expressed in terms of mathematical functions. These mathematical functions are commonly called damage functions.

2.3.2 Available Damage Functions

Bertero and Bresler (1977) proposed a structural damage rating scheme according to the local, global and cumulative damage of the structure using a weighted average approach. An importance factor is introduced for each element depending upon such considerations as life hazard and its associated cost. The resulting damage rating, R which ranges from 0.0 to 1.0, is given as follows:

$$R = \frac{\sum w_i \Phi_i \Omega_i}{\sum w_i \delta_i \tau_i} \quad [2.1]$$

where w_i is the importance factor for i th structural element, Φ_i is the service history coefficient for demand, Ω_i is the response (or demand) in the i th element due to load, δ_i is the service history influence coefficient for capacity, and τ_i is the resistance (or capacity) in the i th element.

For bridge inspection, the rational determination of factors such as Φ , δ , and τ are not simple tasks. It is necessary to conduct further investigations to make this method attractive and practical for bridge engineering practices.

More recently, Bresler and Hanson [1982] introduced a damage rating function for a prescribed event k . The proposed rating for the k th event, D_k which ranges from 0.0 to 1.0, is given as follows:

$$D_k = \frac{\sum w_{ik} d_{ik}}{\sum w_{ik}} \quad [2.2]$$

where w_{ik} is the cumulative importance factor for the i th element and events k , and d_{ik} is the local damage rating for the i th element and k th event. They concluded that further studies are needed to establish appropriate weighting factors.

2.3.3 Proposed Cumulative Rating Function

In practice, the bridge inspector will assess the condition of each type of component based on the rating and perceived importance of its subcomponents. Similarly, the overall rating of a bridge is inferred from the rating of the components. In general, such inference process is influenced by the personal judgment and experience of the bridge inspectors and thus is difficult to model accurately. However, with the development of a new theory, called the theory of fuzzy sets, such subjective judgment can be handled in a systematic fashion.

A cumulative rating function, which is a modified version of the Bresler and Hanson's cumulative damage function, is suggested to model the inspector's inference process. The cumulative rating function is as follows:

$$\bar{R} = \frac{1}{\sum w_i} * \sum (w_i * r_i) \quad [2.3]$$

where w_i is the importance coefficient of the i th component, and r_i is the local rating of the i th component. However, unlike Bresler and Hanson's model, the parameters here are not crisp sets but rather fuzzy sets. Such modifications allow the uncertainty and imprecision that are inherent in the inspection information to be accounted for systematically.

2.4 Fuzzy Inspection Techniques

The imprecision surrounding a bridge inspection situation is basically of two types. One is statistical in nature called random uncertainty and is associated with observed information such as in measurements. The other type, which covers human based uncertainty, is due to "vagueness" of a problem or lack of understanding of a system and is typically associated with knowledge such as in structural behavior. The fuzzy logic theory can be employed to handle imprecision due to human based uncertainty.

Successful applications of the fuzzy sets theory in medicine, economics, and engineering have proven that this theory is a useful tool for handling subjective information in decision making processes.

In the civil engineering area, the theory of fuzzy sets has been suggested for combining the evaluations of weld quality and metal fatigue [Bowman and Yao 1983; Bowman 1985; Bowman et al. 1985]. The proposed method

for combining the evaluations of weld quality for each flaw type is to examine a range in the behavior that corresponds to either no interaction or complete interaction of the weld discontinuities. The upper and lower limit of this range is obtained using algebraic sum and union of fuzzy sets, respectively. This approach can be adopted for bridge condition evaluation.

Watada et. al [1984] employed fuzzy quantification theory to deal with assessment of existing structures. A three-step assessment procedure was proposed: (a) translation of linguistic values into fuzzy grades; (b) estimation of total damage; and (c) linguistic matching of fuzzy grade of the total damage. Statistical data required by this approach are not available for the present study.

Juang and Elton [1986] proposed a systematic approach to evaluating earthquake intensity based on building damage records. The damaging effect of the earthquake on a particular type of building was evaluated using the following equation:

$$E_A = \frac{\sum (A_i * W_i)}{\sum W_i} \quad [2.4]$$

where E_A is the fuzzy set representing expected earthquake damage to evaluated buildings; A_i is the fuzzy set that represents the damage state i ; and W_i is the fuzzy set representing the chance for any building to be in the damage state i . The summation, multiplication, and division in this equation involves fuzzy arithmetic based on fuzzy extension principle proposed by Zadeh, who is the founder of fuzzy sets. This solution technique can be adopted to solve the proposed cumulative rating function described by Equation 2.3.

More recently, Dong and Wong [1985] presented an algorithm for performing extended algebraic operations such as those encountered in risk analysis under fuzzy conditions. The algorithm makes use of the alpha-cut representations of fuzzy sets and interval analysis. The possibility of failure and the severity and reliability estimate for each subcomponent are used to calculate the total risk of the component, R , according to the weighted average rule:

$$R = \frac{\sum (w_i * r_i)}{\sum w_i} \quad [2.5]$$

where w_i denotes the weight (severity of loss) and r_i denotes the possibility of failure of the i th subcomponent. Discretization is used on the membership value rather than the support. The virtues of the proposed algorithm is its simplicity in form and efficiency in computation especially for complex, real-world applications [Dong et al. 1985; Dong and Shah 1987; Dong and Wong 1987]. The proposed algorithm for computing Equation 2.6 can be modified for the present study.

2.5 Concluding Remarks

Existing and deteriorating bridges are extremely complex systems for which the condition is difficult to evaluate. Bridge inspection is by nature a subjective process which does not lend itself to precise results. The inherent uncertainty in the inspection parameters, together with the needs for intuition and judgment during inspection, often resulted in the difficulties of maintaining consistency in bridge condition assessment. Thus the use of inconsistent or weak bridge inspection data may not be commensurate with the accuracy desired by a rigorous bridge management system.

The main thrust of the present work is to develop an approach that will yield condition ratings with minimal inconsistencies. To reduce such inconsistencies, it is proposed that the evaluation of the complex structure be decomposed into an evaluation of the simpler subcomponents. Such decomposition reduces the overall complexity of the original problem and minimizes the likelihood of committing significant errors and omitting significant components in the analysis. A cumulative rating function is proposed for combining the subcomponent condition ratings based upon the importance of each component. To deal with both uncertainty and impreciseness, the theory of fuzzy sets is employed. The fuzzy operation implemented by the cumulative rating function involves fuzzy arithmetic.

CHAPTER 3

3.0 BRIDGE CONDITION ASSESSMENT

3.1 Introduction

3.1.1 General Remarks

As mentioned earlier, bridge inspection provides the essential information required by a bridge management system; a system that will assist decision makers in finding optimal bridge improvement strategies. Although the development of bridge management system has been partially motivated by the successful implementation of pavement management systems, there are many dissimilarities between these two systems. Many problems experienced in the development of a bridge management system are often not encountered in a pavement management system. This is because bridges are generally much more complex systems with many components and constituent subcomponents. Each subcomponent may have different material properties, geometric configurations, and may be subjected to different loading and environmental conditions. Such diversity and individuality are unique characteristics of bridges.

In pavement condition assessment, individual pavement sections are normally considered to have homogeneous material and structural characteristics [Andonyadis et al. 1985; Gunaratne 1984]. Consequently, the solution techniques available for pavement management systems are generally inappropriate for bridge management systems. Nevertheless, as in a pavement management system, inspection rating information forms the foundation of a bridge management system. Regardless of the sophistication in the analytical procedures of a bridge management system, the results of the analysis depend on

the quality of the inspection data. Hence, one of the most important tasks within the framework of a bridge management system is to ensure the accuracy and reliability of the inspection data.

3.1.2 Background

Before discussing in subsequent sections the specific bridge inspection procedure, it is important to describe the general background against which the present work has been undertaken.

As pointed out earlier, the actual behavior and performance of a bridge upon completion are generally different from the results generated by idealized mathematical models employed in the design phase. Thus the adequacy of a bridge structure is never known but can merely be estimated. As a result, there is a need for subjective judgment and intuition in the bridge inspection process. To maintain the accuracy of the inspection data, the inherent inconsistencies associated with subjective judgment must be considered, or at least kept to a minimum.

Hence the justification of the present study is that a bridge management system would yield good improvement strategies so long as the input data is obtained in a systematic and reliable fashion. The thrust of the present work is to achieve better quality control of the input data through minimizing human biases.

3.2 Bridge Inspection

3.2.1 Life Cycle of a Bridge

An understanding of the life cycle of a bridge provides valuable insight for the present work. Figure 3.1 presents a schematic diagram depicting the

Figure 3.1 A General Life Cycle of a Bridge

general life cycle of a bridge. At the beginning in the life of a bridge, information from the site investigation is incorporated into the design process. An iterative analysis process using generalized mathematical models subjected to deterministic loadings is then performed to obtain the optimal design.

As in most engineering structures, bridges start to deteriorate the moment they are built. Thus, the first inspection of a bridge occurs thirty days after its completion. Subsequent inspections are then performed biennially. Field inspection data as well as previous inspection records and bridge drawings provide most of the information required in determining the condition of a bridge.

3.2.2 Purposes of Bridge Inspection

A systematic and periodic inspection of bridges is necessary for the following reasons:

1. To insure the discovery of any critical structural damage at an early date.
2. To provide a record of periodic inspections showing bridge condition.
3. To determine the extent of deterioration and need for repairs as a basis for the recommendations.

As will be seen later, the present inspection scheme yields low precision data. The inspection scheme is geared towards preventing catastrophic bridge failure through repairs on the basis of individual merits without considering their impacts on the network level.

3.2.3 Inspection Procedures

A schematic diagram depicting some of the tasks performed by a bridge

inspector is shown in Figure 3.2. Normally, the initial office work performed by a bridge inspector before going to the field includes reviewing bridge drawings and other construction documents, reviewing previous inspection and repair records, and scheduling bridges to be inspected for the day, taking into account the weather, stream levels, traffic volumes and bridge location [AASHTO 1976; AASHTO 1978]. Frequently, a bridge inspector inspects between 4 to 6 bridges in a day, often alone.

In accordance with the Federal Bridge Inspection Plan, a bridge inspector is required to assess the condition of each subcomponent on a numerical scale ranging from 0 to 9 where 0 and 9 correspond to "total damage" and "no damage", respectively [FHWA 1979; FHWA 1988]. The Bridge Inspector's Training Manual, which was developed by a joint Federal-State task force and published by the U.S. Department of Transportation [FHWA 1971], provides some general guidelines for bridge inspection. This manual discusses some of the typical types of bridge components and constituent subcomponents, and the common causes and types of deterioration. It also provides some procedures for the bridge inspectors to follow when rating the condition of the various subcomponents. The exact definition of each numerical rating excerpted from the inspector's training manual is presented in Table 3.1. Generally speaking, the assessment of each subcomponent rating does not pose a problem to bridge inspectors because the assessment procedure is much simpler and has homogeneous material and structural characteristics.

The condition rating of each of the three major components (deck, superstructure, and substructure) is inferred from the numerical rating of their respective subcomponents. According to a recent FHWA bridge management study [FHWA 1987], a high degree of ambiguity in the condition rating of the major components is unavoidable because they represent the aggregate ratings of

Figure 3.2 Flow Diagram of a Simplified Bridge Inspection Procedure

Table 3.1 Definitions of Bridge Condition Numerical Ratings

<u>Rating</u>	<u>Description of Bridge Condition</u>
9	New Condition
8	Good Condition - No Repairs Needed
7	Generally Good Condition - Potential Exists for minor maintenance
6	Fair Condition - Potential exists for Major Maintenance
5	Generally Fair Condition - Potential exists for Minor Rehabilitation
4	Marginal Condition - Potential Exists for Major Rehabilitation
3	Poor Condition - Repair or Rehabilitation Required Immediately
2	Critical Condition - The need for Repair or Rehabilitation is Urgent. Facility Should Be Closed Until the Indicated Repair is Complete
1	Critical Condition - Facility is Closed. Study Should Determine the Feasibility for Repair
0	Critical Condition - Facility is Closed and is Beyond Repair

several subcomponents. The component rating process is generally influenced by the personal judgment and experience of a bridge inspector and thus is difficult to quantify numerically. Because there are presently no guidelines available for bridge inspectors to perform this procedure, they will consciously or subconsciously develop their own personal procedure after years of experience. The major problem with each inspector having a personalized inference approach is that, depending on the number of years of experience and perhaps engineering education or amount of training received, the final condition assessment of a given bridge will invariably be different. While this inconsistency may not be significant enough to endanger the safety of bridge users, it can cause problems where these data are used in a bridge management system. The optimal improvement strategies for the state-wide bridges may not be found if each bridge inspector at the district level has a different bridge assessment approach.

3.3 Inspection Modeling

3.3.1 Decomposition of a Bridge

As pointed out earlier, a bridge in the present work is decomposed into three main components: deck, superstructure, and substructure. Each component is further divided into simpler subcomponents. In the present study, the deck, superstructure and substructure has 13, 16 and 20 subcomponents, respectively. Of course, a bridge can be divided into more components and each component can be further sub-divided into still simpler subcomponents if such refinement is warranted. However, it should be cautioned that such subdivision may render the original problem intractable for practical use.

In the present work, the decomposition of the components into simpler subcomponents is derived from the items listed in the present inspection

form. Such decomposition is similar to the present procedure, and it permits the use of all existing bridge inspection data bases. A summary of such decomposition arranged hierarchically is presented in Table 3.2.

3.3.2 Cumulative Rating Function

To develop a bridge inspection data enhancement mechanism, it is necessary to tap the knowledge of bridge inspectors. In the present work, interviews were conducted with a number of bridge inspectors in the State of Indiana. (It should be noted that these bridge inspectors were cooperative and knowledgeable.) From these interviews, it was found that personal judgment and experience required in the assessment of a bridge major component can be treated as the subjective assessment of the importance coefficient associated with each subcomponent.

During an inspection, a bridge inspector consciously or subconsciously knows that each subcomponent affects the overall component condition rating differently. Some subcomponents play a more critical role than others. When assessing the overall component condition rating, the bridge inspector must continuously weight the significance of each subcomponent.

The importance coefficient of a particular subcomponent is not a fixed number or constant but varies with the degree of deterioration or the rating of the subcomponent. In other words, as the degree of deterioration increases or the rating index of a subcomponent decreases (decreasing rating value denotes increasing state of deterioration) the importance coefficient of the subcomponent increases. These importance coefficients, if plotted on a graph with the abscissa denoting decreasing state of deterioration and the ordinate indicating increasing importance, will generally produce a monotonic de-

Table 3.2 Decomposition of a Bridge

creasing importance function. The shape of an importance function of a subcomponent is generally a unique characteristic of that subcomponent.

Based upon the interviews mentioned earlier, it was found that a inspector must intuitively perform the following steps during an inspection:

1. Evaluate the rating of each subcomponent type based on the existing condition and on the type and severity of deterioration.
2. Assess the importance coefficient of the various subcomponents.
3. Decide upon the overall condition rating of each of the three major components.

The emphasis of this study is on steps two and three. The evaluation of the rating in step one is a simple task because each subcomponent generally has homogeneous material and structural characteristics. The importance functions in step two are obtained by sending out questionnaires to bridge inspectors and engineers. Step three can be represented mathematically by employing a cumulative rating function as follows:

$$\bar{R} = \frac{1}{\sum w_i} * \sum (w_i * r_i) \quad [3.1]$$

where w_i denotes the importance factor of the i th subcomponent, r_i denotes the local rating index of the i th subcomponent, and $\bar{R}$ represents the overall component rating index. It should be noted that for the purpose of bridge management, the rating of the deck, superstructure and substructure are not combined to obtain the overall bridge rating. The superstructure and substructure condition rating are used in the same category in the bridge management system, while the deck condition rating is used in a different category.

Because the importance coefficients, w , and subcomponent ratings, r , in the cumulative rating function are imprecise quantities, they are best modeled using the theory of fuzzy sets.

3.3.3 Ascertaining Data Reliability

The significance of the reliability, uniformity, and consistency of the inspection data in a bridge management system was well discussed in both the FHWA and NCHRP bridge management study [FHWA 1987; Hudson et al. 1987]. The need for better quality control of the data used in bridge management systems was emphasized.

One of the important features of the proposed bridge condition data enhancement mechanism is that it can be also used to verify the reliability and accuracy of the deck, superstructure and substructure data before entering the bridge management system. The data generated by the proposed mechanism can be compared with previous data on the same bridge to identify major discrepancies.

3.4 Bridge Inspection Reporting Systems

3.4.1 Inspection Forms

In Indiana, a bridge inspector uses a standard form, called the Bridge Inspection Field Report, for recording and reporting the condition of a bridge. The Bridge Inspection Field Report as the name implies is used in the field to record the condition of a bridge. A sample copy of an Indiana State Bridge Inspection Field Report is shown in Appendix C. This form is designed to serve two purposes. First, it forms a permanent record of the bridge condition at the time of inspection. Such record is not only useful for future references but also it protects the State from legal litigation on the

ground of negligence in maintenance and inspection. The second purpose is that it provides the basis for completing the Structural Inventory and Appraisal Sheet (SI&A).

To provide a complete and thorough inventory of the nation's bridges and to compile a report concerning defense bridges and highway facilities, the Federal Highway Administration requires a Structural Inventory and Appraisal Sheet for each bridge in every state. A sample of the Structural Inventory and Appraisal Sheet is also included in Appendix C. The Structural Inventory and Appraisal sheet is presently used to meet National Bridge Inspection Standards and to consider highway bridge replacement or rehabilitation needs. A sufficiency rating is assigned to each bridge based on the information and data contained in this sheet. In Indiana, the SI&A sheet for each bridge is filled and updated at the central office based on the bridge inspection field reports submitted by each bridge inspector.

It should be noted that the FHWA has recently published a revised edition of the recording and coding guide for structures inventory and appraisal [FHWA 1988]. IDOH is also in the process of updating its bridge inspection forms in order to conform to the FHWA requirements. Consequently, the appraisal sheets to be used in the future would be different than those shown in Appendix C. However, most of the items that are of concern to the present study are not changed in the 1988 FHWA Guide.

3.4.2 Revisions of the Inspection System

None of the present bridge condition reporting forms, neither the Bridge Inspection Field Report nor the Structure Inventory and Appraisal sheet, is explicitly designed to serve the needs of a bridge management system. Even though the data from the Structural Inventory and Appraisal sheet is present-

ly used in considering highway bridge replacement or rehabilitation needs, it cannot meet the demands of a rigorous bridge management system because it lacks the necessary details. The information in this sheet may be adequate for a rough estimate of the State's bridge condition but it is not detailed enough for deciding bridge improvement strategies.

The present field inspection form should also be revised to better serve the needs of a bridge management system. The first modification is that a separate form should be used for each bridge type. The second modification is that the deck, superstructure and substructure should each include more subcomponents while eliminate some existing irrelevant items. It should be noted that the bridge condition enhancement computer program developed in the present study can be easily modified to satisfy these revisions.

A third revision which may simplify the bridge inspector's work and reduce the ambiguity in rating somewhat is to use verbal rating with fewer categories such as "Very Good", "Good", "Fair", "Poor" and "Very Poor" instead of the numerical estimates ranging from 0 to 9. One of the findings of the FHWA bridge management study is that ambiguity in a rating system arises from the lack of specificity in the numerical rating definitions [FHWA 1987]. Since each numerical code carries a linguistic meaning such as "Good", "Poor", etc., the use of linguistic rating instead of numerical code may reduce the overall ambiguity in the rating system. The use of linguistic rating descriptors, instead of precise rating numbers, is known to improve the consistency in the ratings of the assessors in a number of psychological studies [Schmucker 1984]. However, this modification may involve further training of inspectors and it is unlikely to be adopted at the moment. Consequently, it is assumed that the present inspection rating scheme would continue to be used. The bridge condition enhancement program developed in the

present study is designed such that it can readily accept either the numerical or the linguistic rating scheme.

Thus, the only modification needed for the present work is that the subcomponent ratings, instead of the overall deck, superstructure and substructure ratings, are entered into the bridge management system. Although this is a significant modification, it does not render the existing bridge inspection data bases useless. The bridge management system will generate the three components condition rating automatically using the cumulative rating function described earlier.

3.5 Sufficiency Rating

Bridge condition ratings are used in the FHWA sufficiency rating scheme. The sufficiency rating is computed using the AASHTO Sufficiency Rating Formula which evaluates the factors indicative of the condition of a bridge. It is intended as a means of deciding how worthy the bridge is in serving the public now and in the future. This method assesses the sufficiency of a bridge.

The sufficiency rating is based on a 0-100 scale. A rating of 100 represents an entirely sufficient bridge whereas a rating of 0 indicates an entirely deficient bridge. Bridges with a sufficiency rating lower than 80 are currently eligible for federal funding of rehabilitation. The bridges with ratings below 50 can be either replaced or rehabilitated under the current federal program, while bridges with ratings of 50 through 80 generally can be only rehabilitated.

The AASHTO Sufficiency Rating Formula has three general categories with the following maximum assigned relative weights:

1. Structural Adequacy and Safety:	55%
2. Serviceability and Functional Obsolescence:	30%
3. Essentiality for Public Use:	15%

The structural adequacy and safety category consists primarily of the ratings of the superstructure and substructure. If the bridge is a culvert without a clearly defined superstructure and substructure, then the rating of the culvert is used. Serviceability and functional obsolescence are made up of items such as the approach roadway alignment, underclearance, deck condition, deck geometry, average daily traffic and the number of lanes on the bridge. The essentiality for public use depends on whether the bridge is on the defense highway, and the average daily traffic and the detour length when the bridge is closed.

If the sufficiency ratings are 50 or more, the formula provides for an additional special reduction up to 13% for long detour lengths, for guardrails and bridge railings which do not meet current standards, and for structure types such as suspension and movable bridges. These special considerations may qualify some bridges for federal bridge replacement funds which otherwise would not ordinarily be eligible.

Within each general category, various items are weighted. When the substructure or superstructure is entirely deficient, the sufficiency rating is further reduced by 55%, whereas if it is in marginal condition the sufficiency rating is further reduced by 25%. If the structure is in fair condition no further deduction is permitted.

The Federal Highway Administration has broad eligibility criteria and its definition of a deficient bridge includes a wide variety of structural inadequacies and conditions. The manner in which the Federal Highway Administra-

tion defines deficiency in bridges is important to state engineers because a bridge must be deficient and should have a sufficiency rating of 80 or less to qualify for Federal bridge replacement funding. The Federal Highway Administration considers a bridge structurally deficient if either the deck, superstructure, substructure or culvert has a condition rating of 4 or less on a 0-9 scale. A bridge is functionally obsolete if the deck geometry, underclearance or approach roadway alignment has a condition rating of 3 or less on a 0-9 scale.

3.6 Project Selection

Rehabilitation is generally less expensive than replacement, because in rehabilitation part of the bridge is left in place. During rehabilitation most of the major defects are corrected. Due to outside constraints such as the requirement of maintenance of traffic during construction, high cost of relocation or replacement, lengthy involvement of environmental analysis and outcome of public hearings, rehabilitation may be the only alternative for many bridges, particularly in a large city or urban areas.

Several states use various methods to select bridge projects for funding. Some have selected projects on a first-come, first-serve basis while others consider a variety of factors by using computer-based systematic analysis. Each state normally uses the sufficiency ratings to identify eligible projects. Besides the sufficiency ratings, factors such as the effect on industry and commerce, type of bridge, continuity of route, future potential for an increase in the volume of traffic, and the number of injuries and fatalities should be considered when bridges are ranked and selected for funding. While one state emphasizes traffic flow, another may focus on level of service and safety. Generally, project selection is focused on bridges which are in the worst condition and are in need of replacement or rehabili-

tation with some flexibility for state and local governments. Such flexibility is fully explored in the development of a bridge management system.

3.7 Concluding Remarks

At the moment and in the near future, bridge inspectors will continue to play an important role in taking care of the nation's bridges. During an inspection, bridge inspectors are frequently required to use their judgment before deciding on the condition of a component. The condition of a component represents the aggregate ratings of several subcomponents. To combine the various subcomponent condition ratings, the bridge inspector must determine the importance of the various subcomponents. Since each bridge inspector generally perceives the importance of each subcomponent differently, the discrepancies and inconsistencies in the overall component rating among the inspectors cannot be neglected.

The thrust of the present work is to develop a mechanism that will combine the subcomponent ratings in a systematic fashion. A proposed cumulative rating function is employed to perform this combination process. The various importance coefficients were elicited through questionnaires. Since the importance coefficients are imprecise quantities, the theory of fuzzy sets was employed to account for the imprecision in these quantities.

It is also recognized that the present inspection scheme is functioning satisfactorily. However, for an effective bridge management program, some modification in the present set-up is necessary. The proposed revision is that the various subcomponent ratings instead of the overall component ratings be entered into the bridge inspection program. Such revision will minimize the inconsistencies associated with the bridge inspection and condition monitoring procedure.

4.0 LOAD CARRYING CAPACITY OF BRIDGES

4.1 Introduction

4.1.1 General Remarks

Much research effort has been devoted to the study and development of procedures for assessment of bridge load carrying capacity during the last two decades [OECD 1979]. In this chapter, the available bridge load carry capacity assessment techniques are reviewed and their advantages and shortcomings highlighted. However, because of the abundance of material related to this subject matter, the review is not intended to be all inclusive. Nevertheless, an in-depth treatment of the state-of-the-art regarding bridge load capacity evaluation suitable for the present study and how the resulting bridge capacity rating can be best incorporated in a bridge management system is presented.

4.1.2 Background

Bridges are integral elements of modern road networks with often serious social, political and economic consequences when their load-carrying capacity is impaired. The public rightly expects the enormous amount of resources invested in bridges to be utilized in the most economical manner possible at an acceptable level of convenience and safety. To meet this expectation, an efficient bridge management system is needed.

In a bridge management system, the load capacity rating can be treated as an input parameter that indicates the strength or ability of a bridge to carry current traffic loadings. The importance of accurate load capacity

assessment has caught the attention of many bridge engineers. Bridges are being subjected to an ever increasing volume of heavy truck traffic, and a growing number of exceptional live loads such as heavy construction equipment and farming vehicles [OECD 1976, 1979]. This, together with the effects of normal wear and tear, has made the assessment of bridge load carrying capacity a vital step in preventing catastrophic bridge failure. From this perspective, the bridge load carrying capacity rating should be explicitly considered in deciding on maintenance, strengthening, or even replacing of bridges.

4.1.3 Condition Rating Versus Load Capacity Rating

The distinction between the assessment of bridge condition and load carrying capacity is not clearly defined in the literature. In general, a bridge condition assessment does not require the bridge inspector to perform any in-depth structural analysis. As discussed in Chapter 3, it is performed primarily on the basis of subjective judgment, experience and intuition of the bridge inspector. The bridge condition rating can be treated as an indicator of the degree and importance of deterioration of a bridge with respect to its initial condition at the time of construction.

The assessment of the safe-load carrying capacity of a bridge, on the other hand, does require the assessor to perform some structural analyses. It generally demands an objective rather than subjective assessment on the part of the bridge inspector. Unlike the rating of bridge condition which is generally expressed in terms of a numerical value on a 0 - 9 scale, the rating of bridge load carrying capacity is expressed in terms of vehicular loadings such as H or HS loading or its equivalent in tons.

In Indiana, the load carrying capacity of a bridge is determined by an engineer's assistant from the central office. Such assessment has already

been performed on approximately 4,000 bridges in Indiana. Currently, bridge load capacity ratings are determined as if the bridges were in good condition. Since the existing state of deterioration of a bridge is not taken into account, such assessment does not have to be repeated regularly.

However, for the purpose of bridge management, it is proposed that the load capacity assessment be performed whenever significant deterioration occurs. The bridge load carrying capacity assessment should take into account the existing state of deterioration [AASHTO 1978] and should reflect its present state of adequacy.

Conceptually, the bridge load carrying capacity rating is as important an indicator of the needs of a bridge as its condition rating. However, the question as to which is a better indicator is difficult to decide. It depends on the emphasis and policy of each highway agency. Ideally, both indicators should be used in any bridge management system. However, if a state has many bridges with posted load limits, then the load carrying capacity rating would be a suitable indicator of the bridge needs.

The significance of load capacity rating versus condition rating can be illustrated through an example. In the United States, there are still many arch bridges in service today. A number of these obsolete bridges are not in good physical condition due to their years of wear and tear. However, structurally, they have been found to be generally adequate to carry today's traffic loading because of their unique method of construction. Conversely, there are many well-maintained bridges that are in good physical condition but are not adequate for the ever increasing heavy truck loadings. This is because they were designed for a lower loading specification in the earlier days, typically H15 and HS15 AASHTO truck loadings.

In Indiana, there are approximately 191 existing bridges that were designed for H15 AASHTO design truck loading and another 24 for HS15 loading. Clearly, in determining the needs and improvement strategies of bridges in Indiana, the load carrying capacity rating should be included in the analysis.

An accurate assessment of the load carrying capacity of a bridge is usually a difficult assignment. The true load carrying capacity of a bridge is never precisely known because it is generally computed using idealized analytical models. Thus, the emphasis here is not on methods of determining the true bridge load capacity but rather on systematic procedures for estimating the true load capacity for the network of bridges.

4.2 Bridges in Indiana

Before discussing the suitability of any load carrying capacity assessment technique for the present work, an understanding of the general characteristics and condition of bridges, and the agency policy or philosophy in Indiana is essential. This is because the selection of an appropriate bridge load carrying capacity evaluation technique depends on the bridge characteristics and agency policy.

4.2.1 Bridge Characteristics

As noted earlier, there are 17,658 bridges in the State of Indiana in 1988. Of these, 5,290 bridges are under the care of state highway agency. The remaining bridges are under the custody of local agencies on railroads. The present work concentrates primarily on bridges on the state highway system.

There are six state highway districts taking care of the 5,290 state-owned bridges in Indiana. The distribution of these bridges among the districts is shown in Figure 4.1. Each district has a bridge inspector responsible for all bridges in that district. In accordance with the Federal Inspection Plan, each inspector is required to inspect each bridge at least biennially. Based on the number of bridges and available working days, it can be readily shown that each inspector must daily inspect at least 1-1/2 bridges for Fort Wayne and 3 bridges for Greenfield and the other districts varying in between. Since load capacity evaluation is a time consuming process, bridge inspectors are not responsible for any load capacity evaluation. This task is done by personnel at the central office.

Many states including Indiana are confronted on one hand with a growing number of aging bridges, and, on the other hand, with the task of handling growing traffic volumes. Figure 4.2 depicts a plot of the cumulative density function (cdf) of the total number of bridges in Indiana at the end of each year. This figure is drawn using information extracted from the Indiana bridge inventory report. From this figure, it can be concluded that approximately fifty percent of the bridges in Indiana were built before the mid-1950s. In essence, many bridges that were built in the earlier days and are still in service today may not have been designed to handle the growing number of heavy vehicles. The load carrying capacity of these older bridges must be computed using today's design loading rather than their original design loading. Clearly, careful assessment of the load carrying capacity of these older bridges is an important step in a bridge management process.

4.2.2 Classification of Bridges In Indiana

Bridges that are presently being built in Indiana can be broadly grouped into five categories: reinforced concrete slab, prestressed box beams, pre-

Figure 4.1 Distribution of State-Owned Bridges in Indiana

Figure 4.2 Cumulative Density Function of Bridges in Indiana by Year

stressed I-beams, steel beams and steel girders [Tee 1985; Tee et al. 1986]. However, many older bridges in service today such as arches and trusses are not classified under any of these categories. Figure 4.3 presents a schematic diagram of the various types of bridges that are still in service in Indiana. Assessment of the load carrying capacity for some of the obsolete bridges may require special attention because their design information may no longer be available. Since these obsolete bridges are likely candidates for replacement and are more prone to failure, a conservative assessment of their load carrying capacity may be permissible.

4.3 Deficiencies on Bridge Elements

4.3.1 General Remarks

According to the Manual for Maintenance Inspection of Bridges [AASHTO 1978], the assessment of a structure for its load capacity must start with a thorough field investigation. All physical features of a bridge which have an effect on the structural integrity should be examined and any damaged or deteriorated sections should be noted so that their effect on the bridge can be properly evaluated in the analysis. For example, if a steel member is corroded or a concrete section is damaged, the loss in cross-sectional area should be determined so that the net section can be calculated.

An understanding of the functional role of each type of bridge element is essential to the bridge engineer who is involved in load carrying capacity assessment. The bridge engineer must be able to identify the critical members from the redundant members. Deficiencies on redundant or secondary members are generally neglected in load carrying capacity assessment because they do not affect the capacity of the bridge significantly. The deficiency type is also very important in the assessment of the bridge load carrying capacity.

TYPES OF BRIDGES (INDIANA 1986)

Figure 4.3 Types of Bridges in Indiana

4.3.2 Common Deficiencies On Certain Bridge Elements

As mentioned earlier, a bridge can be divided into three major components: deck, superstructure and substructure. Each component is comprised of a number of different elements or subcomponents. An exploded view of a typical highway bridge showing the location of the various subcomponents is presented in Figure 4.4 [FHWA 1970]. From this diagram, it can be seen that a bridge is comprised of many different elements. However, only those elements that are critical to the bridge load carrying capacity assessment are examined herein.

Before discussing the kinds of deficiencies that should be explicitly considered in load capacity assessment, it should be noted that the type of materials used in the construction of a bridge will establish the particular kinds of deterioration or deficiencies that can be expected to be found during the inspection. For example, concrete deteriorates due to scaling, spalling, and cracking. Steel is susceptible to corrosion, while timber is prone to decay, weathering and insect attacks.

Concrete beams and deck may be cast as a single monolithic section or composed of individual units tied together by diaphragms and end beams. The beams may be either reinforced, prestressed, precast or cast-in-place. These features must be explicitly considered in any load carrying capacity evaluation. During an inspection, the beams are checked for diagonal cracking near the supports, which may indicate incipient shear failure, and for spalling at points of bearing where friction from thermal movement and high edge pressure exists [FHWA 1971]. In the area of tension steel, the bridge inspector usually can expect flexural cracks. Discoloration of the concrete surface may be an indication of corrosion of reinforcing steel and concrete deterioration.

Figure 4.4 Exploded View of a Typical Highway Bridge (FHWA 1970)

Any reduction in cross sectional area of concrete section or reinforcing steel must be noted and accounted for when determining the load carrying capacity of the structure [AASHTO 1978].

Steel beams and girders, which may be considered as main members, transfer all deck loads to the substructure of the bridge. There are generally two types of steel beams and girders: rolled wide flange section for less than 100 feet spans and built-up plate girders for spans longer than 70 feet. Steel box girders, which have high torsional resistance, are not commonly used in Indiana and are excluded from this discussion.

During inspection, the bridge inspector usually looks for steel corrosion along the beams/girders, around bolts and rivet heads, and at gusset, diaphragm, and bracing connections. If rusting or deterioration is evident, the members are examined for possible reduced cross sectional area using calipers and corrosion meters [FHWA 1971]. Such reduction in cross sectional area may cause a reduction in load carrying capacity [FHWA 1970].

Areas around rivets or bolts and along seams of built-up members and splices are examined for signs of slippage. The welds are examined for cracks, particularly in the areas where stress concentration could cause fatigue deterioration, and at unusual types of weld connections or connections to which access would have been difficult for the welder. The general alignment of the girders is checked by sighting along the members for misalignment or distortion commonly caused by overstress, collision, or fire damage [White et al. 1981]. If any of these problems exists, the load carrying capacity of the bridge should be fully investigated.

The end connections of floor beams are usually checked for corrosion. This is particularly critical at the location where the end connections are

exposed to deicing chemicals. The top flange of floor beams should also be examined for corrosion, especially near the end connections and at points of bearing. On end floor beams, the connections are examined for cracks in the welds or slippage in the bolts or rivets. If there is any severe corrosion, weld cracking, or bolt slippage, the safe load capacity of the bridge should be investigated.

For steel stringers, corrosion can be a problem at places where moisture from the deck may accumulate and also at the end connections around rivets, bolts, and bearings. For timber stringers, crushing and decay, sagging, and splitting are common problems and should be examined carefully.

Diaphragms are transverse members between main girders or stringers which brace and stiffen the longitudinal members. They distribute loads laterally and resist torsion. Diaphragms on shallow steel stringer bridges are usually channel or wide flange sections connected to the stringer webs with plates and angles or by welding. Cross frames are commonly used on the deeper built-up beams. Concrete diaphragms cast monolithically with the beams are often used on concrete bridges. The diaphragm or cross bracing forms the secondary system of the bridge and is less important in the load carrying capacity evaluation. As a result, minor deterioration on the bracing system are often ignored in a load carrying capacity evaluation.

A truss consists of members which are generally under axial tension or compression loading only. The greatest usefulness of trusses are for bridges with relatively long spans where dead load is significant. However, because of their high cost of fabrication and the availability of more economical alternatives, they are no longer being built in many states. In Indiana, there are 145 steel truss bridges still in service today.

Truss members may be connected with rivets, bolts, or pins. Although the configuration of trusses varies widely, the essential components are common to all. Corrosion due to moisture and deicing chemical is a major problem in truss bridges. End posts and interior members are vulnerable to collision damage from passing vehicles. Buckled or misaligned members may severely reduce the load carrying capacity of the truss.

Bearings transmit and distribute the superstructure loads to the substructure, and they permit the superstructure to undergo necessary movements without developing harmful overstresses. Bearings are of two general types, fixed and expansion. The principal difference between these bearings types is that fixed bearings permit rotation but resist translation, while expansion bearings permit both rotation and translation of the superstructure. The most common problem in bridge bearings is the result of deterioration due to corrosion. This deterioration results in a loss of contact area between the load carrying member and the support. The safe load carrying capacity then becomes a function of the remaining contact area of the bearing device.

According to the AASHTO Manual for Maintenance Inspection of Bridges [AASHTO 1978], the weaker element of most bridges is the superstructure, not the piers and abutments. For this reason, the load capacity rating of a bridge is generally determined from an analysis of the superstructure unless unusual structural configurations warrant analysis of the substructure. Thus, the deterioration of piers and abutments is presently ignored in the determination of safe load carrying capacity.

With the advent of the computer age, structural analyses using the finite element method can be readily employed to determine the load carrying capacity of a bridge subjected to the various types of deterioration. Un-

fortunately, this method is time-consuming and often impractical for everyday use. Simple, approximate methods have been developed by the Federal Highway Administration and are presented next.

4.4 Load Capacity Evaluations

4.4.1 Types of Capacity Rating

According to the Manual for Maintenance Inspection of Bridges [AASHTO 1978], each highway bridge should be rated at two load levels by methods which properly account for the strength of the materials of construction in their current state. At the upper load level, the capacity rating is referred to as the operating rating. The operating rating will result in the absolute maximum permissible load level to which the structure may be subjected. Special permits for heavier than normal vehicles may be issued only if such loads are distributed so as not to exceed the structural capacity determined by the operating rating [AASHTO 1978]. The operating rating is recorded in the Structural Inventory and Appraisal Sheet under Item 64 as presented in Appendix C. As mentioned earlier, this information is not determined by the bridge inspector but by the central office personnel.

At the lower load level, the capacity evaluation is referred to as the Inventory Rating. The inventory rating will result in a load level which can safely utilize an existing structure for an indefinite period of time [AASHTO 1978]. The inventory rating is recorded in the Structural Inventory and Appraisal Sheet under Item 66 (see Appendix C).

4.4.2 Methods of Load Capacity Ratings

As mentioned earlier, with some exceptions, the weaker elements of the

older bridges are usually in the superstructure, not in the substructure. Thus, a practical procedure in making the safe load evaluation is through the normal sequence of calculations starting with the deck, stringers, floor beams, trusses, girders, etc. The deck, however, is seldom the controlling member in a structure with longitudinal stringers. The live load moments in longitudinal stringers and girders produced by typical loads can be found using moment tables or simple structural matrix analysis.

The allowable stresses in bridge elements may be determined using AASHTO Specifications as found in the Manual for Maintenance Inspection of Bridges [AASHTO 1978] and the Standard Specifications for Highway Bridges [AASHTO 1983]. The allowable stress is generally taken as the stress assumed in the design of the structure or the stresses recommended by AASHTO at the time of construction.

As previously mentioned, there are two levels of capacity recommended by AASHTO specifications for bridges. The inventory rating may be defined as the load which produces a stress in the critical bridge subcomponent of 0.55 times the yield stress or the allowable stress used in design. The operating rating is defined as the maximum load that should be allowed on a bridge under any circumstances. The maximum stress at the operating rating is 0.75 times the yield stress, or 1.364 times the allowable stress used in design. Although either the working stress method or the load factor method may be used in determining safe load carrying capacity, the load factor method as described in the AASHTO Interim specifications for Bridges [AASHTO 1976a] is probably the simpler method and will be discussed herein. The rating factors for inventory and operating level are as follows:

Inventory Level

$$RF_{(inv)} = \frac{M_u - 1.3 M_D}{1.3 (1.67 M_{L+I})}$$

Operating Level

$$RF_{(opr)} = \frac{M_u - 1.3 M_D}{1.3 (M_{L+I})}$$

where RF denotes the rating factor, M_u denotes the ultimate moment capacity of beam, M_D denotes moment created by dead load and M_{L+I} denotes moment created by rating vehicle load plus impact. The load capacity rating is determined by multiplying the rating factor by the standard load number [White et al. 1981]. For example, if the standard load were an HS20 truck, the capacity rating would be the rating factor times 20.

To compute the M_{L+I} , the loading is first positioned for maximum moment and its moment computed. It is then increased by the impact factor for the bridge. The M_u is equivalent to the maximum strength that can be sustained by the section. Methods for computing M_u can be found in the Standard Specifications for Highway Bridges. The AASHTO equation for M_u for singly reinforced concrete beams (or doubly reinforced beams with compression reinforcement neglected) is as follows:

$$M_u = 0.9 A_s F_y (d - a/2)$$

where A_s denotes the total area of steel, F_y denotes the yield strength of steel, d denotes the distance from the centroid of the tension steel to the outermost compression fibers of the beam, and a is the depth of the equivalent Whitney's stress block.

The algorithm for load capacity evaluation of a bridge is as follows:

- Step 1. Determine the net cross-sectional properties and the appropriate stress rating level. Any loss in cross-sectional area due to damage or deterioration must be calculated.
- Step 2. The dead load for the structure is computed.
- Step 3. The available live load capacity is determined by taking the difference between total load capacity and the dead load.
- Step 4. The required live load capacity is determined for the structure using an AASHTO standard design vehicle, usually the HS20 truck load.
- Step 5. The rating factor is obtained by taking the ratio of the available live load capacity and the required live load capacity of the design vehicle.
- Step 6. The load capacity rating of the structure is computed by multiplying the rating factor by the standard vehicle load.

A flow diagram summarizing this algorithm is presented in Figure 4.5. For the purpose of illustrating this algorithm, an example problem is presented next.

4.4.3 Example Problem

The reinforced concrete slab bridge shown in Figure 4.6 is assumed to experience a 10 percent reduction in reinforcement cross-sectional area due to corrosion. Find the inventory and operating ratings for the concrete slab bridge.

General Information:

Clear Span = 20 ft.
 Effective Span = 21 ft.
 Rating Vehicle = HS20 Loading
 Grade 40 Steel ($f_y = 40$ ksi)
 Concrete Strength ($f'_c = 3$ ksi)
 Slab Thickness = 14 in.
 Effective Steel Depth = 12.5 in.
 Reinforcement = $1.57 \text{ in}^2/\text{ft}$.

Flow Diagram For Load Capacity Evaluation

Figure 4.6 Concrete Slab Bridge Configuration for Example Problem.

Dead Load:

$$\begin{aligned} \text{Concrete} &= (14/12) * 150 &= 175 \text{ lb/ft}^2 \\ 3 \text{ in. bituminous} &= (3/12) * 144 &= 36 \text{ lb/ft}^2 \\ W &= 211 \text{ lb/ft}^2 \end{aligned}$$

$$\begin{aligned} M_D &= \frac{W * l^2}{8} = \frac{211 * (21)^2}{8} = 11631 \text{ ft-lb/ft} \\ &= 11.6 \text{ ft-kips/ft} \end{aligned}$$

From AASHTO HS20 truck table in the Manual for Maintenance of Bridges [AASHTO 1970]

$$\begin{aligned} M_{L+I} &= 21800 \text{ ft-lb/ft} \\ &= 21.80 \text{ ft-kips/ft} \end{aligned}$$

10% reduction of #8 bar has an area of 0.71 in.²,

$$A_s = 2 * 0.71 = 1.42 \text{ in.}^2$$

$$\begin{aligned} T &= A_s f_y \\ &= 1.42 * 40,000 \\ &= 56,800 \text{ lb} \\ &= 56.8 \text{ kips} \end{aligned}$$

$$a = \frac{T}{0.85 f'_c b}$$

$$a = \frac{56.8}{0.85 * 3 * 12}$$

$$a = 1.85 \text{ in.}$$

$$\begin{aligned} M_u &= 0.9 (A_s f_y) (d - a/2) \\ &= 0.9 (56.8) (12.5 - 1.85/2) \\ &= 591.71 \text{ in.-kips/ft} \\ &= 49.31 \text{ ft-kips/ft} \end{aligned}$$

$$\begin{aligned} RF(\text{inv}) &= \frac{M_u - 1.3 M_D}{1.3 (5/3 * M_{L+I})} \\ &= \frac{49.31 - 1.3 (11.6)}{1.3 (5/3 * 21.80)} \end{aligned}$$

$$RF_{(inv)} = 0.7$$

$$RF_{(opr)} = \frac{M_u - 1.3M_D}{1.3(M_L + I)}$$

$$= \frac{49.31 - 1.3(11.6)}{1.3 * 21.80}$$

$$RF_{(opr)} = 1.20$$

Hence, the bridge inventory rating is $0.7 * HS20 = HS14$ and the bridge operating rating is HS24. Since the operating rating is greater than the design load, the bridge is adequate for the present traffic loading and no load posting is required.

4.4.4 Computer Aided Analyses

The determination of the load carrying capacity of a bridge is a time-consuming process depending on the bridge type, extent of deterioration, number of spans, etc. As mentioned earlier, under the present policy of inspecting three to four bridges a day, a bridge inspector usually does not have enough time to carry out any in-depth load capacity assessment. Bridge inspectors in Indiana and many other states are not required to determine the load carrying capacity of a bridge. They are only required to write down the posted load capacity of the bridge, if any. The posting of load capacity is performed by specialized personnel from the central office. Consequently, the present load carrying capacity may not reflect the adequacy of a bridge at the time of inspection.

However, for the purpose of bridge management where subtle changes in load capacity may cause a bridge to be repaired, the load carrying capacity should be evaluated after each inspection. Clearly, any time-consuming load capacity evaluation approach will not be appropriate under the present cir-

cumstances. It may also involve certain changes in agency policy, the use of appropriate bridge inspection software, and perhaps the use of a hand-held computer at the site as presently being done in the State of Colorado.

4.4.5 Bridge Capacity Analysis Systems

Numerous computer-aided bridge capacity analysis systems are readily available as tools in determining the safe load-carrying capacity of bridges. A survey of AASHTO software [AASHTO 1985] revealed more than 250 software packages of different sizes and complexities for analyzing different bridges.

One of the earliest systems was the Bridge Rating and Analysis Structural System (BRASS). This program was developed by the Wyoming Highway Department and sponsored by the Federal Highway Administration. The primary goal of this system was to provide a computerized method of determining the inventory rating and operating rating described in the Manual for Maintenance Inspection of Bridges. The basic information required by this system includes span length, cross section dimensions, material properties, type of material, and the type of structure [Wyoming 1973].

The BRANDE system was developed primarily to analyze the grid system of the bridge superstructure [White et al. 1981]. It has the capability of analyzing rigid frames associated with the superstructure. The Control Data Corporation developed the Bridge Analysis and Rating System (BARS). The BARS program has been adopted for bridge load capacity evaluation in Indiana since 1972. The main features of this system are to perform inventory rating, operating rating, load posting ratings, special permit analysis, and analysis for bridge design. Five types of bridge structures may be analyzed: slabs, stringers, floor beams, girders, and trusses. Construction materials that may be used in the analysis include structural steel, reinforced concrete, pre-

stressed concrete, and composite girder-deck systems. The system input information includes the geometry of the structure, member properties, member materials, and loadings. The analysis is based on the working stress method described in the AASHTO specifications.

4.5 Capacity Rating in Bridge Management Systems

At the network level of decision making, improvement strategies are often based on many different factors. Some of the factors are condition rating, load capacity, bridge deck width, vertical clearance and remaining life. The primary interest here, however, is to review how the load capacity rating has been incorporated in some bridge management systems.

In the North Carolina bridge management system, only three bridge characteristics were selected as the most direct measures of bridge needs [Johnston and Zia 1984]. These characteristics were load capacity, clear deck width, and vertical roadway clearances. These bridge characteristics were assigned goals for the service conditions, which vary with traffic volume and functional classification of the roadway. Two levels of these goals were selected: an acceptable level and a desirable level. In establishing acceptable level of service goals for load capacity, the North Carolina Department of Transportation (NCDOT) surveyed the weights of essential service vehicles. Included in the survey were weights of loaded school buses, garbage trucks, etc. Based on the survey results, NCDOT set a minimum acceptable load capacity goal of 16 tons for minor collector and local roads. For the interstate highways, the capacity goal of 33.6 tons corresponding to a single unit truck with three rear axles was selected. A bridge with an operating rating of less than 33.6 tons on the Interstate highways and less than 16 tons on local roads is judged to be unacceptable.

The Pennsylvania bridge management system has three levels of service: minimum acceptable level, minimum design level and desirable design level [Weyers et al. 1984]. For the interstate highway bridges, the minimum acceptable level of load capacity was set at 36 tons which corresponds to HS20. Both the minimum design and desirable design levels for load capacity were set at 45 tons (HS25) for bridges on interstate highway, arterial, collector and local roads.

The Nebraska bridge management system has two levels of service: acceptable and desirable [FHWA 1987]. The acceptable and desirable bridge goals for bridges on interstate highways were both set at HS20.

The Federal Sufficiency Rating formula is widely used as a priority ranking formula. The Sufficiency Rating Formula has three components: structural adequacy and safety (weighted 55 percent); serviceability and functional obsolescence (weighted 30 percent); and essentiality for public use (weighted 15 percent). The load capacity of a bridge determined from the inventory rating is considered under the structural adequacy and safety component. No reduction from the load capacity sufficiency points is necessary if the inventory rating is higher than HS20 (36 tons). One of the shortcomings of the sufficiency rating that is often criticized is that the load capacity reduction is not a function of highway classification. A bridge with low load capacity will be assigned a low sufficiency rating even though the bridge may be in good condition and adequate for the local road traffic.

The priority ranking system in North Carolina utilizes assigned weights of 70, 12, 12, 6 for load capacity, bridge deck width, vertical clearance, and remaining life, respectively. The priority ranking system in Virginia combines level of service concepts with the sufficiency rating formula as-

signed weights of 30, 12, 12, 46 for load capacity, bridge deck width, vertical clearance and sufficiency condition rating, respectively. In Nebraska's priority ranking formula, the assigned weight to load capacity attribute is 50.

Pennsylvania's priority ranking system features both the sufficiency rating and North Carolina's level of service system. The total deficiency rating is a function of load capacity deficiency, clear deck width deficiency, vertical clearance deficiency, bridge condition deficiency, remaining life deficiency, approach roadway alignment deficiency, and waterway adequacy deficiency. The bridge condition deficiency is equal to the sum of bridge deck, superstructure and substructure condition deficiencies.

From the literature review, it can be concluded that bridge load capacity is an important attribute in all bridge management systems. However, the load capacity goals for the various level of services and the assignment of load capacity weights vary significantly among the various systems. The selection of load capacity goals and the assignment of weights should be left to the expertise and judgment of bridge engineers.

4.6 Concluding Remarks

Load carrying capacity assessment plays an important role in determining the needs of bridges. This is partly because some bridges were not designed to carry the current truck traffic. In addition, deterioration due to repeated application of deicing chemicals as well as normal wear and tear can further reduce the load carrying capacity of a bridge.

Unlike the condition assessment, the load carrying capacity assessment is based primarily on objective information. Since the present practice in

Indiana dictates that a bridge inspector inspect between three to four bridges a day, the inspector does not have enough time to assess the load carrying capacity of a bridge. This task is assigned to specialized personnel at the central office. The central office is also responsible for determining and changing the bridge capacity posting. The BARS, which has been used in Indiana since 1972, appears to be serving adequately the needs of Indiana bridges. The load carrying capacity of approximately 4000 bridges has already been determined using this software package.

For the purpose of bridge management, it is proposed that the load carrying capacity of a bridge be determined whenever there is a significant change in the state of deterioration. Such evaluation should explicitly consider the extent of deterioration of the bridge. The load capacity assessment obtained in this manner would provide valuable information regarding the adequacy of a bridge to the bridge management system.

The establishment of load capacity goals for various levels of service and the assignment of load capacity weights are highly non-uniform among the existing bridge management systems. However, the NCDOT load capacity goals and weights for various levels of service appear to be an appropriate set of load capacity goals and weights.

CHAPTER 5

5.0 FUZZY MATHEMATICAL THEORY

5.1 Introduction

5.1.1 General Remarks

One of the aims of the present work is to employ an appropriate and effective technique for modeling the bridge condition inspection process described earlier. As discussed in Chapter 3, the technique deemed most appropriate for the present study involves a relatively new approach called the theory of fuzzy sets. Consequently, this chapter is devoted entirely to an introduction of some of the basic principles and concepts of this theory. A clear understanding of the material presented in this chapter is essential for one to fully appreciate the bridge condition inspection modeling methodology presented in the next chapter.

The treatment of the fuzzy mathematical concepts related to decision making presented herein is not intended to be all inclusive. Much of the material presented herein is available in the literature, although the primary source of information is from the work published by Zadeh, [Dubois and Prade 1980; Zadeh 1965, 1971, 1973, 1975, 1978, 1983, 1985, 1986].

5.1.2 Background - Development of Fuzzy Sets Theory

The fuzzy set theory was developed by Zadeh in 1965. It has certain characteristics of the naive set theory introduced by Halmos in 1960 [Yager et al. 1987]. Zadeh believes that our ability to make precise and significant statements concerning a given system diminishes with increasing complexity of the system, and the closer one examines a real-world problem the fuzzier the manner of solution becomes. As a result, Zadeh was motivated to develop the

theory of fuzzy sets as a tool with which meaningful solutions to complex problems with imprecise information can be found [Zadeh 1973].

Information available for decision makings such as in bridge inspection is generally imprecise and can often be separated into objective and subjective components [Chameau et al. 1983]. The objective component concerns measurable, countable or quantitative information such as the diameter of a reinforcing bar or the width of a concrete crack. The subjective component, on the other hand, includes intangible or qualitative information such as the significance of a crack on a steel member or the strength of a deteriorated bridge. Obviously, the subjective component must involve the wisdom, judgment and experience of a bridge inspector. Although the significance of the subjective component has been well-recognized, there is generally a lack of systematic methods of incorporating this information into the objective bridge inspection system in the literature. This is perhaps due to the fact that subjective information is intangible and thus difficult to quantify into meaningfully terms using existing techniques. However, with the development of fuzzy set theory, there is now a systematic way to quantify imprecise information.

Since the appearance of first paper on the concepts of fuzzy sets in the literature in 1965, there are presently somewhere between 3,000 and 4,000 papers written worldwide on fuzzy sets and their applications [Yager et al. 1987]. Successful applications of fuzzy sets theory in medicine, economics, and engineering, albeit limited, have shown that this theory is indeed a useful tool for handling imprecise information in decision making processes.

5.1.3 Randomness versus Fuzziness

Much of the decision making process in the real world occurs in environ-

ments in which the parameters or input variables are not precisely known. This imprecision in information can often be attributed to both fuzziness and randomness in the parameters. However, in most decision making the primary source of imprecision of the input variables is fuzzy in nature rather than random [Yager et al. 1987].

Traditionally, to deal quantitatively with imprecision, the concepts and techniques of probability theory are often employed. The validity of employing probability theory to deal with imprecision in decision making is questionable because imprecision, whatever its nature, cannot be equated totally with randomness.

To fully appreciate the usefulness of the fuzzy set theory or the appropriateness of using this theory, a clear understanding of the distinction between randomness and fuzziness is necessary. Zadeh stated that randomness has to do with uncertainty concerning membership or nonmembership of an object in a nonfuzzy set. Fuzziness, on the other hand, has to do with classes in which there may be grades of membership intermediate between full membership and nonmembership. Reflecting this distinction, the mathematical techniques for dealing with fuzziness using fuzzy set theory are quite different from those of probability theory [Zadeh 1978]. Furthermore, because the notion of probability measure in probability theory corresponds to the simpler notion of membership function in the theory of fuzziness, it is generally advantageous to deal with imprecision through the techniques provided by the theory of fuzzy sets rather than through the employment of the conceptual framework of probability theory [Yager et al. 1987].

Hence, the techniques and concepts provided by the theory of fuzzy sets are selected for modeling the decision making process in the present bridge

condition inspection study. The need for decision making occurs frequently during a bridge inspection, both in the physical condition assessment and the safe load capacity evaluation. The condition (damage) assessment involves the determination of the extent of damage or deterioration on a bridge, whereas the load capacity (safety) evaluation concerns the safety and adequacy of the bridge subjected to today's traffic loads and environmental conditions.

5.2 Fuzzy Sets

5.2.1 The Mathematical Concepts

The exact relationship of the notion of a fuzzy set to that of an ordinary set can be seen most clearly when one recalls the definition of the characteristic function of a set. For an ordinary set (A) in the space of discrete points $X=x$, the characteristic function (f_A) is of the following form:

$$f_A(x) = \begin{cases} 1 & \text{if } x \text{ is in the set } A \\ 0 & \text{if } x \text{ is not in the set } A \end{cases}$$

Alternatively, it may be simply defined as follows:

$$f_A(x) : U \rightarrow \{0,1\}$$

The characteristic function maps the universe U to the set of two elements $\{0,1\}$. In other words, an element is either in the set or not in the set. The braces, $\{ \}$, here denote a binary choice of membership values.

Conversely, the characteristic function of a fuzzy set (A) in the space of discrete points $X=x$ is defined as follows:

$$f_A(x) : U \rightarrow [0,1]$$

The characteristic function becomes a membership function which associates with each point in A , a real number in the interval $[0,1]$. The square brackets, $[\]$, here denote a continuum of possible choices of membership values.

Hence, a fuzzy set (A) in the space of discrete points $X=x$ is defined as follows:

$$A = U_i (\mu_A(x_i) | x_i, i=1,2,\dots,n) \quad x \in X$$

where $\mu_A(x)$ is termed the grade of membership of x in A and the notation $\in$ means "belongs to". In the literature, the union sign (U) may be replaced by the summation sign (Σ) or omitted altogether. For a continuous fuzzy set, the integration sign ($\int$) is used in place of the union sign (U).

The membership space of a fuzzy set is the interval $[0,1]$ with 0 and 1 representing the lowest and highest grades of membership, respectively. Thus, the basic assumption is that a fuzzy set (A) can be defined by associating with each element a number between 0 and 1 which represents its grade of membership.

If the range of the characteristic function of a fuzzy set, A , is in fact restricted to just the two values of 0 and 1, then this function reduces to an ordinary characteristic function and A reduces to an ordinary, non-fuzzy set. Thus, the fuzzy set theory contains ordinary set theory as a special case.

The grade of membership, $\mu_A(x)$, can be viewed as the degree of support or belief that the element x belongs to the set A . The construction of this

membership function can be accomplished with the cooperation and assistance of a panel of experts in specific cases.

For the purpose of illustration, suppose A represents a fuzzy set describing the imprecise expression "old" or the set of ages of bridges which are old. Clearly, a bridge under forty years old is "not old" if the design life is assumed to be seventy years. Thus, the degree of membership for the function defining the expression "old" for a bridge less than forty years old is 0 and greater than seventy is 1. The grade of membership between forty and seventy years should be based on the "belief" and judgment of a panel of bridge engineers. For illustration purposes, it is assumed here that the grade of membership for the function defining the expression "old" between forty and seventy years follows a parabolic curve.

Proceeding in the same fashion, the membership functions for other linguistic expressions describing the state of a bridge according to its age can also be constructed. The membership functions defining the linguistic expressions for the state of a bridge are depicted graphically in Figure 5.1.

5.2.2 The Background of Fuzzy Operations

Basic concepts and operations related to fuzzy sets A and B in the space of discrete points $X=\{x\}$ having membership values $\mu_A(x)$ and $\mu_B(x)$, $x \in X$ respectively are summarized in this section. It should be noted that some of the concepts and operations discussed herein may not be directly related to the present work but are included for comparison purposes.

a) Normality

A fuzzy set A is normal if and only if $\sup_x \mu_A(x)=1$, that is, if the

Figure 5.1 Examples of Membership Functions for Bridge Classification on the Basis of Bridge Age.

maximum value of $\mu_A(x)$ over all X is unity. A fuzzy set is subnormal if it is not normal [Yager et al. 1987]. For example, the set

$$A = [1|1, 0.8|2, 0.6|3]$$

is normal, while

$$B = [0.6|1, 0.8|2, 0.6|3]$$

is subnormal. The non-empty subnormal fuzzy set, B , can be normalized by dividing each $\mu_B(x)$ by the factor $\text{Sup}_X \mu_B(x)$. The normalization of B results in

$$\text{NORM}(B) = [0.75|1, 1|2, 0.75|3]$$

The fuzzy set, B , is empty if and only if $\mu_B(x) \equiv 0.0$ for all $x \in X$.

b) Equality

Two fuzzy sets A and B are equal if and only if

$$\mu_A(x) = \mu_B(x) \text{ for all } x \in X.$$

c) Containment

A fuzzy set A is contained in another fuzzy set B if and only if

$$\mu_A(x) \leq \mu_B(x) \text{ for all } x \in X.$$

d) Fuzzy Union and Fuzzy Intersection

Two basic operations available for aggregating fuzzy sets are fuzzy union and fuzzy intersection. The intersection of A and B is denoted by $A \cap B$

B and is defined as the largest set contained in both A and B . The membership function of $A \cap B$ is given by

$$\mu_{A \cap B} = \text{Min} (\mu_A(x), \mu_B(x)), x \in X$$

where $\text{Min}(a,b) = a$ if $a \leq b$ and $\text{Min}(a,b) = b$ if $a > b$. In infix form, using the conjunction symbol $\wedge$ in place of Min can be written more simply as

$$\mu_{A \cap B} = \mu_A(x) \wedge \mu_B(x).$$

For example, if the universe $U = \{1,2,3,4,5,6\}$ and the meanings of u and v are expressed as follows:

$$u = [0.8|3, 1|5, 0.6|6]$$

$$\text{and } v = [0.6|3, 1|4, 0.5|6]$$

$$\text{then } u \cap v = [0.6|3, 0.5|6]$$

The union of $A \cup B$, is defined as the smallest fuzzy set containing both A and B . The membership function of $A \cup B$ is given by

$$\mu_{A \cup B} = \text{Max} (\mu_A(x), \mu_B(x)), x \in X$$

where $\text{Max}(a,b) = a$ if $a \geq b$ and $\text{Max}(a,b) = b$ if $a < b$. In infix form, using the disjunction symbol $\vee$ in place of Max can be written more simply as

$$\mu_{A \cup B} = \mu_A(x) \vee \mu_B(x).$$

As an illustration, for the u and v defined earlier,

$$u \cup v = [0.8|3, 1|4, 1|5, 0.6|6]$$

The fuzzy union and fuzzy intersection operations have a very easily understood graphical representation as shown in Figure 5.2. The fuzzy union provides an "optimistic" aggregate by assuming credibility in opinions ex-

Figure 5.2 Fuzzy Intersection and Fuzzy Union

pressed in either A or B, whereas the fuzzy intersection provides an "pessimistic" aggregate by assuming credibility only in the combined opinion of A and B [Chameau et al. 1983].

e) Algebraic Product

The algebraic product of A and B is denoted by AB and is defined as follows:

$$\mu_{A.B}(x) = \mu_A(x) \cdot \mu_B(x), \quad x \in X$$

Thus, if $A = [0.5|2, 0.8|5]$
 and $B = [0.4|2, 0.8|3, 0.6|5]$
 then $AB = [0.20|2, 0.48|5]$

f) Algebraic Sum

The algebraic (probabilistic) sum of A and B is denoted by A + B and is defined as follows:

$$\mu_{A+B}(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) \cdot \mu_B(x), \quad x \in X$$

Thus, if $A = [0.2|2, 0.5|4]$
 and $B = [0.5|2, 0.4|4]$
 then $A + B = [0.6|2, 0.7|4]$

The $\cdot$ (product) and $+$ (sum) operators are associative but not distributive. On the other hand, the min and max are commutative, associative and mutually distributive operators.

g) Fuzzy Complementation

The complementation operation from traditional set theory can also be

extend to fuzzy set theory. The definition proposed by Zadeh for the complement of a fuzzy set A is as follows:

$$\mu_{A'}(x) = 1 - \mu_A(x), \quad \text{for all } x \in X.$$

Thus, if $A = [\text{arch}, \text{truss}, \text{suspension}, \text{cable-stay}]$ is a class of rare bridges in Indiana and $\mu_A(\text{arch}) = 0.8$, then $\mu_{A'}(\text{arch}) = 0.2$.

This definition has the property that if the fuzzy set A is reduced to an ordinary non-fuzzy set, then this definition of the complement and the traditional set theory definition yield identical results.

h) Fuzzy Concentration - CON(A)

$$\mu_{\text{CON}(A)}(x) = (\mu_A(x))^2 \quad \text{for all } x \in X$$

Since the degree of membership for any element of a fuzzy set is a real number between 0 and 1, the square of that degree of membership will also be between 0 and 1. The CON operator decreases the degree of membership for all elements, except those with degree of membership of 0 or 1. Furthermore, it decreases the membership proportionally more than for elements with high degrees of membership. For example, if the meaning of the term "good" is defined by

$$\text{good} = [1|1, 1|2, 0.7|3, 0.4|4]$$

$$\text{then } \text{CON}(\text{good}) = [1|1, 1|2, 0.49|3, 0.16|4]$$

i) Fuzzy Dilation - DIL(A)

$$\mu_{\text{DIL}(A)}(x) = (\mu_A(x))^{0.5} \quad \text{for all } x \in X$$

The effect of DIL is opposite to that of CON, which reduces the magnitudes of $\mu_A(x)$ by relatively smaller amounts for those x having higher membership in A

compared to those with low μ_A values. For example, if the meaning of the term "fair" is defined by

$$\text{fair} = [0.5|1, 1|2, 0.8|3, 0.6|4]$$

$$\text{then } \text{DIL}(\text{fair}) = [0.7|1, 1|2, 0.9|3, 0.78|4]$$

As will be seen in Chapter 6, the CON and DIL operations are useful when dealing with fuzzy hedges such as "very" or "generally".

j) Fuzzy Intensification - INT(A)

$$\begin{aligned} \mu_{\text{INT}(A)}(x) &= 2(\mu_A(x))^2, & 0 \leq \mu_A(x) \leq 0.5 \\ &= 1 - 2(1 - \mu_A(x))^2 & 0.5 \leq \mu_A(x) \leq 1.0 \end{aligned}$$

Intensification acts like a combination of concentration and dilation. It raises the degree of membership of some elements and lowers others. Since intensification increases the degree of membership only for the elements that have a degree of membership greater than 0.5 and lowers the degree of membership of elements whose degree of membership is less than 0.5, intensification heightens the contrast between the elements that are more than half in the set and those that are less than half in (Yager et al. 1987). An example of the INT operation is shown in Figure 5.3.

k) α cut - A_α

A_α comprises all elements of X whose degrees of membership in A are greater than or equal to α , $0 < \alpha \leq 1$.

$$A_\alpha = \{ \mu_A(x) \geq \alpha : x \in X \}$$

The membership function of a fuzzy set A expressed in terms of the characteristic function $\mu_{A_\alpha}(x)$ of its α -level is:

Figure 5.3 Fuzzy Intensification

$$\mu_A(x) = \sup_{\alpha} \min(\alpha, \mu_{A_{\alpha}}(x))$$

where

$$0 < \alpha \leq 1$$

and

$$\mu_{A_{\alpha}}(x) = \begin{cases} 1 & \text{if } x \in A_{\alpha} \\ 0 & \text{otherwise} \end{cases}$$

A fuzzy set A may be decomposed into its level-sets through the resolution identity such that

$$A = \sum_{\alpha} \alpha A_{\alpha}$$

where αA_{α} is the product of a scalar α with the set A_{α} and the $\sum$ denotes union of A_{α} , with α ranging from 0 to 1.

For example, a fuzzy set A may be represented as

$$A = [0.1|1, 0.3|2, 0.5|6, 0.9|7, 1|9]$$

or

$$A = [0.1|1+0.3|2+0.5|6+0.9|7+1|9]$$

where + means union.

A can be rewritten as

$$\begin{aligned} A = & 0.1[1|1+1|2+1|6+1|7+1|9] + \\ & 0.3[\quad 1|2+1|6+1|7+1|9] + \\ & 0.5[\quad \quad 1|6+1|7+1|9] + \\ & 0.9[\quad \quad \quad 1|7+1|9] + \\ & 1.0[\quad \quad \quad \quad 1|9] \end{aligned}$$

Thus, $A_{\alpha=0.1} = [1, 2, 6, 7, 9]$

$$A_{\alpha=0.3} = [2, 6, 7, 9]$$

$$A_{\alpha=0.5} = [6, 7, 9]$$

$$A_{\alpha=0.9} = [7, 9]$$

$$A_{\alpha=1.0} = [9].$$

As will be described in Chapter 6, this concept can be used in knowledge combination.

1) Fuzzy Number

A fuzzy number is a number characterized by a possibility distribution. In general, a fuzzy number is either a convex or a concave fuzzy set [Zadeh 1979]. A special case of fuzzy number is an interval. The degree of belongingness of the element x in a fuzzy number is denoted by $\mu(x)$. For example, the fuzzy number about 5 can be represented with the following L - R type membership function:

$$\mu_5(x) = \begin{cases} (x-3)/2 & 3 \leq x \leq 5 \\ (7-x)/2 & 5 < x \leq 7 \\ 0 & \text{otherwise} \end{cases}$$

The concept of fuzzy number is particularly useful in the present work because the numerical condition ratings described in Chapter 3 are fuzzy numbers.

m) Fuzzy Relation

The concept of a relation plays an important role in the fuzzy sets theory. Fuzzy relation in this theory is analogous to the joint probability in the probability theory Brown and Yao [1982].

$$\begin{aligned} \text{Let } A &= (\mu_A(x_i) | x_i; 1 \leq i \leq m) \\ B &= (\mu_B(y_j) | y_j; 1 \leq j \leq n) \end{aligned}$$

where A and B are fuzzy sets. The fuzzy relation, R , of A and B is defined by

$$R = A \times B = \sum_{i=1}^m \sum_{j=1}^n \mu_R(x_i, y_j) | (x_i, y_j)$$

in which $\mu_R(x_i, y_j) = \min [\mu_A(x_i), \mu_B(y_j)]$.

n) Fuzzy Composition

The above conditional expression $R = A \times B$ is a fuzzy relation between A and B. The fuzzy composition of A and R is defined by

$$B = A \circ R = \text{Sup}_y \text{Min} [\mu_A(x), \mu_R(x,y)].$$

This equation is particularly useful in fuzzy Markov Chain modelling. In a fuzzy Markov Chain, the fuzzy transition probability matrix is treated as the fuzzy relation, R, and the initial state probability is the fuzzy set A. The unknown state is, of course, the fuzzy set B.

5.2.3 Development of Membership Functions

Although the fuzzy membership function is, in some respects, similar to the probability density function, they are conceptually different. For example, the idea that a whale has a degree of 0.4 in the membership of a fuzzy class called "fish" does not mean that 40% of the whale is fish. In general, a probability measure describes the uncertainty in randomness of an event whereas the membership value provides a criterion for the belongingness of an element in an ill-defined set.

Although many ideas and methods for membership function development have been suggested in the literature, there is as yet no widely agreed approach to estimate membership functions. These ideas can be grouped under two broad categories: the statistical approach and the group decision approach. Some of the suggested membership development methods include exemplification, pairwise comparison, point estimation and interval estimation [Chameau and Santamarina 1986]. Other known approaches for assigning membership values that will not be discussed herein are curve fitting and fuzzy entropy.

In the method of exemplification proposed by Zadeh [1965], a number of experts are asked whether a certain event is in an ill-defined set. Each possible linguistic response such as "more or less true", "more or less false", "false", etc., will have a pre-assigned numerical value. The membership function for that particular event is the average of the numerical values. The main advantage of this approach is that the membership function is directly determined from the responses. The major limitation of this approach is that it is cumbersome.

In the pairwise comparison method developed by Saaty [1974], the degrees of support of two events in a fuzzy set are compared one at a time. A comparison matrix $[A]$ of size $n \times n$ is constructed where an element a_{ij} is the ratio of the degrees of support of event i and event j in the fuzzy set. If $W=(w_1, \dots, w_n)$ is the vector containing the relative weights of event i in comparison to all events, Saaty [1974], showed that the maximum eigenvalue (δ) has the following form:

$$[A - \delta I] W = 0$$

The degrees of belongingness are components of the eigenvector corresponding to the maximum eigenvalue (δ) . In other words, the membership of an i th element can be obtained by normalizing w_i values. This method gives a measure of the consistency, but not the quality, of the responses from each expert. The determination of membership functions from this approach is rather tedious. Further, this method should not be used for qualities or issues that are controversial. Only if individuals have a clear understanding of the problem and if such understanding is generally agreed upon, may the method be applied.

The point estimation approach requires the experts to select an event in an ill-defined set that best answers the question. The membership value of each event is proportional to the number of responses favoring that particular event. This approach is simple. However, there exists a paradox between the fuzziness of the question and the preciseness of the answer.

The interval estimation approach is similar to the point estimation approach except the experts are required to select an interval of possible events that best answers the question. The membership value of a particular event corresponds to the number of intervals that contain that event. This method is also simple. However, it implies that each point within each interval has a uniform distribution which may not necessarily be valid in certain cases.

Each method has its own advantages and limitations. One method may be more appropriate than another depending on the context of its application. However, in general, the only requirement of assigning membership support is that it produces numbers reflecting the strength of an element's membership in a fuzzy set.

The use of triangular and trapezoidal shaped membership functions has been criticized as being unrealistic in their representation of uncertainty, particularly because of the sharp transitions that may result [Hinkle et al. 1986]. For more gradual transitions, standard functions are usually employed. Three such standard functions, the S-function (monotonic), Z-function (monotonic) and the π -function (bell-shaped) are defined as follows [Yager et al. 1987]:

$$\begin{aligned}
 S(x:a,b,c) &= 0, & x &\leq a \\
 &= 2\{(x-a)/(c-a)\}^2, & a &\leq x \leq b \\
 &= 1-2\{(x-a)/(c-a)\}^2, & b &\leq x \leq c \\
 &= 1, & x &\geq c
 \end{aligned}$$

where $b=(a+c)/2$, and

$$\begin{aligned} Z(x;a,b,c) &= 1, & x &\leq a \\ &= 1 - 2\{(x-a)/(c-a)\}^2, & a &\leq x \leq b \\ &= 2\{(x-a)/(c-a)\}^2, & b &\leq x \leq c \\ &= 0, & x &\geq c \end{aligned}$$

where $b=(a+c)/2$

$$\begin{aligned} \text{and } \pi(x;b,c) &= S(x;c-b, c-b/2, c), & x &\leq c \\ &= 1 - S(x;c, c+b/2, c+b), & x &\geq c \end{aligned}$$

In S and Z functions, parameter b is the cross-over point and in π -function, is the bandwidth, i.e., the separation between the cross-over points of a π -function and c is the central point at which $\pi=1$. The Z -function is a mirror image of S -function. Typical S and π functions are plotted as shown in Figure 5.4.

It is to be mentioned here that the assignment of the membership function of a fuzzy set is subjective in nature, and reflects the context in which the problem is viewed. It cannot be assigned arbitrarily. Details about the evaluation of membership functions for the present work will be explained in Chapter 6.

5.2.4 Linguistic Hedges

Hedges and primary terms can be used to specify a linguistic variable. For example, the numerical rating "5" as described in the National Bridge Inspection Standards has a linguistic equivalence of "generally fair". In this example, the definition of the primary term "fair" is modified by the hedge "generally". Thus, a hedge is not modeled by a fuzzy set but rather is modeled as an operator on the primary term [Zadeh 1973].

Plots of S and π functionsFigure 5.4 Plots of S and π Functions

Hedges can be divided into two somewhat fuzzy categories defined as follows [Yager et al. 1987]:

- Type 1. Hedges in this category can be represented as operators acting on a fuzzy set. Typical hedges in this category are: very, more or less, much, slightly, and generally.
- Type 2. Hedges in this category require a description of how they act on components of the operand. Typical hedges in this category are: essentially, strictly, in a sense, virtually, etc.

In the present work, only Type 1 hedges are relevant. It is convenient to begin the discussion of Type 1 hedges by considering a simple and basic hedge, namely, "Very".

Let A be a fuzzy set in the Universe (U) representing the meaning of a primary term such as "old". Let A^* be the fuzzy set representing the meaning of the term "very old". The hedge "very" can be viewed as an operator which transforms the fuzzy set A into the fuzzy set A^* .

Specifically, the CON operator is assumed for this illustration such that

$$\text{VERY(OLD)} = \text{CON(OLD)}$$

or

$$A^* = \text{CON}(A)$$

or, more explicitly

$$A^* = A^2.$$

Hence, if

$$A = \mu_1^1 y_1 + \dots + \mu_n^1 y_n, \quad y_i \in Y, \quad i = 1, \dots, n$$

then

$$A^2 = \mu_1^2 y_1 + \dots + \mu_n^2 y_n$$

If A representing the term "old" is characterized by a membership function of the form shown in Figure 5.5, then the membership function of A^* representing the term "very old" can be plotted as shown in the same figure.

Another hedge "generally" is also useful for the present work. It is a member of a family of hedges which have the effect of reducing the grade of membership of those objects which are in the "center" of a class and increasing those which are on its periphery. It can be approximated by the following expression

$$\text{Generally } A = \text{NORM} [\neg \text{CON}^2(A) \cap \text{DIL} (A)]$$

in which the term $\neg \text{CON}^2$ serves to reduce the grade of membership of those points which are close to zero, while DIL increases the grade of membership of points which are remote from zero. The $\neg$ sign denotes the complementation operator.

The characterization of hedges of Type 2 is considerably more complex than that of hedges of Type 1. It is formulated as a fuzzy algorithm involving Type 1 hedges. For example, $x=\text{decent}$, with the components of x assumed to be $x_1=\text{kind}$, $x_2=\text{honest}$ and $x_3=\text{polite}$. It is further assumed that x is a convex combination of components, that is,

$$\mu = w_1\mu_1 + w_2\mu_2 + w_3\mu_3$$

where the $w_i, i=1, \dots, n$ are weights whose sum is unity and μ is the grade of membership. The magnitude of w_i is a measure of the importance of the attribute x_i .

It should be emphasized that the above representations are intended mainly to illustrate the use of hedges rather than to provide accurate defi-

Figure 5.5 Example of the Hedge Very on the Primary Term Old.

dition of the hedge in question. The use of this concept for the representation of condition ratings is further explored in Chapter 6.

5.2.5 Extension Principle

The extension principle introduced by Zadeh in 1975 is the accomplishment of yet another milestone in the history of fuzzy sets. This principle, which forms the mathematical backbone of the fuzzy sets theory provides a framework or mechanism for extending non-fuzzy mathematical concepts to deal with fuzzy quantities and subsequent derivation of new fuzzy equations. It is partially responsible for the rapid expansion of the fuzzy sets theory to real-world applications.

As mentioned earlier, the fundamental difference between the classical set theory and fuzzy set theory is that a variable in the former set has a precise value whereas a variable in the latter set is defined by a function - the membership function. A fuzzy variable is completely defined by a range of values with degree of membership attached to each possible value.

Using the extension principle, the image of a fuzzy set under a mapping f is just the fuzzy set formed by mapping each of the points of the fuzzy set and associating with the mapped points the same degree of membership as their pre-images under f . In other words, if f is a mapping from $X_1, \dots, X_r$ to a universe Y such that $y=f(x_1, \dots, x_r)$, the fuzzy sets $A_1, \dots, A_r$ in respective spaces $X_1, \dots, X_r$, will induce a fuzzy set B on Y through f such that the membership function of B in terms of A is as follows:

$$\mu_B(y) = \sup_{y=f(x_1 \dots x_r)} \min [\mu_{A_1}(x_1), \dots, \mu_{A_r}(x_r)]$$

The above equation appears complex because it has more than one variable. For functions with one variable, the extension principle appears simple. Let f be a mapping from X to Y such that $y=f(x)$, then

$$\mu_B(y) = \mu_B(f(x)) = \mu_A(x)$$

Alternatively, the extension principle can be illustrated as follows:

Let f be a mapping for U to V , that is, $f: U \rightarrow V$. Thus,

$$v = f(u)$$

where u and v are elements of U and V , respectively.

Let $A = \{\mu_A(x) | x, x \in U\}$ be a fuzzy subset of U . Then the definition of f can be extended to include the set of fuzzy subsets of U as follows:

$$\begin{aligned} f(A) &= f\{\mu_A(x) | x, \quad x \text{ is an element in } U\} \\ &= \{\mu_A(x) | f(x), \quad x \text{ is an element in } U\} \end{aligned}$$

For example, assume that f is the operation of squaring. Then, for the set $A = [0.3|0.5, 0.6|0.7, 0.8|0.9, 1.0|1.0]$

$$f(A) = [0.3|0.25, 0.6|0.49, 0.8|0.81, 1.0|1.0]$$

Zadeh has defined a fuzzy analog of independence called non-interactive. Simply stated, a fuzzy subset of $U_1 * U_2$ is non-interactive if it is separable into its two projections. Thus, to "reconstruct" such a non-interactive fuzzy set, the fuzzy cross product should be used.

Let

$$\begin{aligned} A &= \{\mu_A(x) | x\}, & x &\in U_1 \\ B &= \{\mu_B(y) | y\}, & y &\in U_2 \end{aligned}$$

The fuzzy cross-product of $A * B$

$$A * B = \{ \min(\mu_A(x), \mu_B(y)) | (x, y) \}$$

Therefore, the definition of $f(A)$ (a non-interactive fuzzy set) becomes

$$f(A) = \{\min [\mu_A(x), \mu_B(y)] | f(x, y), x \in U_1, y \in U_2\}$$

Using the extension principle, the definition of fuzzy addition ($A + B$), fuzzy multiplication ($A * B$) and fuzzy division ($A \div B$) are as follows:

$$\begin{aligned} f(A, B) &= A + B \\ &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | f(x, y), x \in A, y \in B \} \\ &\quad \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x + y], x \in A, y \in B \} \end{aligned}$$

Similarly,

$$\begin{aligned} A * B &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x * y], x \in A, y \in B \} \\ A \div B &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x \div y], x \in A, y \in B \} \end{aligned}$$

The fuzzy addition, multiplication and division are used extensively in the present work. For example, if A and B are two fuzzy sets defined as follows:

$$A = [.2 | 1, 1.0 | 2, 1.0 | 3, .2 | 4]$$

and

$$B = [0 | 1, .2 | 2, .9 | 3, .7 | 4]$$

then, according to the foregoing definition of fuzzy product,

$$\begin{aligned} A * B &= \{ \min(.2, 0) | [1 * 1], \\ &\quad \min(.2, .2) | [1 * 2], \min(1.0, 0) | [2 * 1], \\ &\quad \min(.2, .9) | [1 * 3], \min(1.0, 0) | [3 * 1], \\ &\quad \min(.2, .7) | [1 * 4], \min(1.0, .2) | [2 * 2], \min(.2, 0) | [4 * 1], \\ &\quad \min(1.0, .9) | [2 * 3], \min(1.0, .2) | [3 * 2], \\ &\quad \min(1.0, .7) | [2 * 4], \min(.2, .2) | [4 * 2], \\ &\quad \min(1.0, .9) | [3 * 3], \\ &\quad \min(1.0, .7) | [3 * 4], \min(.2, .9) | [4 * 3], \\ &\quad \min(.2, .7) | [4 * 4], \\ &= [0 | 1, .2 | 2, 0 | 2, .2 | 3, 0 | 3, .2 | 4, .2 | 4, 0 | 4, .9 | 6, .2 | 6, .7 | 8, \\ &\quad .2 | 8, .9 | 9, .7 | 12, .2 | 12, .2 | 16] \\ &= [0 | 1, .2 | 2, .2 | 3, .2 | 4, .9 | 6, .7 | 8, .9 | 9, .7 | 12, .2 | 16] \end{aligned}$$

This definition of this fuzzy product can be interpreted as union of intersection of $A*B$.

5.3 Concluding Remarks

The fuzzy mathematical approach is a powerful analytical tool in solving problems where vagueness, imprecision and complexity prevail. Applications of this technique have been suggested for problems as divergent as the computer modeling of the human thought, medical diagnostics, and the operation of concrete plants.

Failure of the traditional statistical or probabilistic approach to deal effectively with imprecision is due to the fact that it can identify only with a membership value which is either 0 or 1. Thus, the traditional approach cannot handle fuzziness in information. The fuzzy sets theory, on the other hand, can handle imprecise information because the degree of belongingness of an element is an ill-defined variable which can take on values ranging from 0.0 to 1.0. The fuzziness is captured in the form of degree of membership.

The extension principle provides a mechanism to extend the domain of a given function to include fuzzy sets. It forms the backbone of the fuzzy set theory. Although the treatment of the fuzzy concepts and principles presented herein is rather brief, it is sufficient for one to understand the fuzzy modeling process presented in the next chapter.

CHAPTER SIX

6.0 BRIDGE INSPECTION MODEL

6.1 Introduction

6.1.1 General Remarks

Use of some of the basic principles and concepts of fuzzy mathematics for developing a bridge condition assessment model is described in this chapter. Engineering judgment is a vital part of the bridge inspection process. As a result, the present work is devoted to understanding the role and importance of engineering judgment in the decision making process during a bridge inspection, and systematic integration of this information with objective information. Such effort is essential to the development of an appropriate and meaningful mathematical model for bridge inspection.

6.1.2 Bridge Inspection In A Fuzzy Environment

Much of the material presented herein is based on information obtained from opinion surveys and interviews with bridge inspectors and engineers. From these interviews, it can be concluded that the condition assessment of a bridge is performed on the basis of imprecise information and to a certain extent on the inspector's experience, judgment and individual intuition.

Traditionally, to quantify personal judgment and imprecise information into precise values, statistical approaches such as probabilistic methods and Bayes' theorem are often employed. Unfortunately, these probabilistic methods have been recently found to be inappropriate for solving decision problems involving human judgment [Yager et al. 1987]. This is because human judgments in decision making are generally non-probabilistic in nature.

With the advent of fuzzy set theory, there now appears to be a logical approach for handling human judgment in a fuzzy environment. Using this theory, uncertainty in human judgment is quantified and expressed in terms of membership functions. Prior to presenting the bridge condition assessment modeling process using fuzzy sets theory, however, it is necessary to briefly recapitulate the basic steps involved in the bridge inspection process as described in Chapter 3 and to identify the stages in which fuzzy mathematical concepts may be applicable.

6.2 Bridge Inspection

6.2.1 Bridge Inspection Process

A bridge is generally divided into three major constituent components: deck, superstructure and substructure. Each component can be subdivided into a number of subcomponents. The subdivision of each component into its subcomponents can be accomplished via an opinion survey of a panel of bridge experts. However, in lieu of such survey, the subdivision of each component into its constituent subcomponents in the present study is obtained by simply adopting the items listed under each component in the field inspection form. Thus, the term "subcomponent" here refers to both structural and non-structural items.

During an inspection, the bridge inspector will first examine and evaluate the extent of damage or deterioration on a subcomponent and then describe the physical condition of that subcomponent using a numerical rating scale. This process is repeated for all subcomponents. The numerical rating is based on a 0 - 9 scale, where 0 and 9 are the linguistic equivalence of "critically damaged" and "undamaged" condition, respectively. The condition rating of each component is then inferred from the condition ratings of its various

subcomponents. Such inference process invariably involves human bias and engineering judgment because the human mind is not very efficient in aggregating imprecise information of these subcomponents simultaneously.

A similar inference process has been previously studied by Scholl et al. [1982] for seismic damage assessment of high-rise buildings in a comprehensive manner. He defined the damage to a component as a function of the deterioration of its various subcomponents. However, after a thorough literature search, it is apparent that such inference process for a bridge has not been studied previously. As a result, the bridge condition inference process has remained as privileged information of relatively few inspectors and is transferred to younger inspectors primarily through many years of working experience and individual intuition. Thus, much research effort in the present work is devoted to the understanding of this inference process.

6.2.2 Inference Process in Bridge Inspection

Based on information gathered primarily from interviews with a group of bridge inspectors, it can be concluded that the judgment, experience and intuition which are often needed in the bridge inference process can be lumped together and interpreted as the assessment of the importance or significance of the structural role of a subcomponent as well as its physical condition. In other words, the significance of a subcomponent in the inference process depends on two factors: the importance of its structural function and its physical condition. For the sake of convenience in the present work, the significance of a subcomponent in the inference process is termed as an "Importance Factor". The importance factor resembles a weighting coefficient and is thus appropriately denoted by W .

Each numerical rating has a corresponding linguistic definition that can be represented as a fuzzy number, R . Thus, the inference process model has the following simple mathematical form:

$$\bar{R} = \frac{1}{\sum_i W_i} * \sum_i \{ W_i * R_i \}$$

where $\bar{R}$ is a fuzzy number denoting the resultant rating of a component, R_i denotes the rating of the i th subcomponent, and W_i denotes the importance factor for the i th subcomponent. For simplicity, this equation is termed as the "bridge condition inference equation" in the present study.

The combination of the ratings and their associated importance factors can be viewed as a two-dimensional problem [Tee et al. 1987, 1988]. Before discussing the solution technique to this two-dimensional problem, an understanding of how to determine these fuzzy importance factors and how to represent the numerical ratings as fuzzy numbers is essential to the present work and will be presented next.

6.3 Fuzzy Parameters in Bridge Inspection

6.3.1 Fuzzy Importance Factors

As mentioned previously, there are presently no established guidelines available for the bridge inspector to follow when assessing the significance of each subcomponent with respect to other subcomponents and when aggregating this information in the determination of the overall component condition rating. Thus, most bridge inspectors invariably evaluate and aggregate the importance of the various subcomponents according to their judgment and previous experience. Hence, as mentioned in earlier chapters, it is very

likely that competent bridge inspectors may arrive at a different conclusion for the rating of a given bridge. While such discrepancies may never be significant enough to endanger the safety of the public, it is, nevertheless, undesirable for a comprehensive bridge management system. Consequently, methods were evaluated in the present work to reduce this type of discrepancy. This effort involves the determination of the various importance factors described earlier.

As noted earlier, it is apparent that there are two factors that a bridge inspector must consider before determining the importance of a subcomponent. These factors were found to be a) the structural importance of a subcomponent with respect to the whole structure and b) the extent of damage or deterioration sustained by a particular subcomponent. Thus, the importance factor of a subcomponent is not a constant or a fixed number but varies with the degree of damage sustained by that subcomponent. If a subcomponent sustains no damage or deterioration, then the importance factor is the same as the structural importance of that subcomponent.

To illustrate the point that the importance factor is not a constant, the following hypothetical case is assumed. Suppose a reinforced concrete superstructure has both cracks and corrosion and the condition of both flaws are described by the same rating variable "generally fair". Even though they are both described by the same rating variable, concrete cracks may have more influence on the condition rating than corrosion at this early stage of deterioration. Therefore, deterioration due to concrete cracks may have a higher importance factor than corrosion at this stage. Furthermore, assume that as the concrete cracks propagate and the steel corrosion continues, a stage will be reached whereby both the flaws are described by the same rating variable "poor". At this later stage of deterioration, steel corrosion rather

than concrete cracks may be more influential in initiating structural failure of the member and hence may have a higher importance factor. In short, the importance of corrosion or cracks with respect to the concrete superstructure in this example varies with its condition rating.

In general, the poorer the condition rating of a subcomponent, the higher the importance factor of that subcomponent. Conceptually, the importance factor of each subcomponent should also be a function of the bridge type, loading and environmental conditions, etc. However, for practical purposes, any variation that occurs as a result of these factors can be neglected. This assumption is generally acceptable because the importance factor is a function of the bridge condition rating and any variation due to bridge type, loading or environmental conditions, etc. is reflected in the condition rating itself. For example, a three inch crack may be considered to be in good condition for a large prestressed concrete bridge but in poor condition for a small reinforced concrete bridge. In other words, the condition rating to be assigned to a subcomponent depends on factors such as the extent of damage, the bridge type, size, and loading condition.

The determination of the importance factor of various subcomponents is a particularly challenging task. This is partly because each importance factor is not a constant but varies with its structural importance and condition rating. In lieu of any theoretical analysis and consistent with fuzzy set concepts, these importance factors can be obtained through an expert knowledge survey. In fact, one of the attractiveness of using the fuzzy set concepts in a knowledge survey is that it provides a logical way of modeling the perceptiveness and uncertainty in the expert opinion. Furthermore, because the responses of the experts in any knowledge survey contain human uncertainty rather than statistical uncertainty, the fuzzy logic rather than the

traditional probabilistic approach should be employed. Consequently, the importance factors of various subcomponents were developed from the responses of bridge experts to sets of questionnaires.

6.3.2 Information Survey

A copy of the questionnaire that was drawn up for the purpose of eliciting the importance factors from bridge experts is presented in Appendix B. A total of 46 bridge inspection experts consisting primarily of inspectors, engineers and bridge consultants in Indiana and neighbouring states responded to the survey.

Since the judgment of bridge experts is invariably subjective, fuzzy logic is used to capture this subjectivity in systematically assessing the importance of the subcomponents. Consistent with the fuzzy set concepts, the importance factors are expressed as membership functions. The point estimation approach was employed in constructing the various membership functions based on the responses from the questionnaire survey.

For the purpose of extracting the importance factor, the condition of each subcomponent is considered in terms of five categories: excellent, good, fair, poor, and critical. The importance factor of each subcomponent is thus defined by five membership functions with each corresponding to one of the five condition rating categories. The membership value of each element in a fuzzy set representing a condition rating category is computed based on the number of responses favoring that particular element. The algorithm for the determination of the membership value for each element is as follows:

- Step 1. Compute the number of responses, r_i , favoring each element, i , in the fuzzy set (A) that represents a condition rating category from the questionnaire.

- Step 2. Determine the highest number of responses from the set of number of responses for each element in Step 1, that is, $\text{Sup} \{ r_i \}, i \in A$.
- Step 3. Normalize the membership value of each element by dividing the number of responses of each element, r_i , in the fuzzy set (A) by the highest number of responses, $\text{Sup} \{ r_i \}$, in Step 2.
- Step 4. Where necessary, modify the membership function by the S, Z, or π shape functions.

The idea of importance factors can be best illustrated by examining plots of membership functions for a particular bridge component under different condition states. Figures 6.1 through 6.3 illustrate the membership functions for superstructure floor beams under three different conditions. The degree of importance of the floor beam plotted on the horizontal reference axis varies numerically between 0 and 1.0, with 0 and 1.0 denoting "no structural importance" and "significant structural importance", respectively.

In Figure 6.1, it can be seen that there is strong support (membership value = 1) that floor beams in poor condition are very important (importance=1.0) and no support for poor condition (membership value = 0.0) when the degree of importance is less than 0.67. For the floor beams in fair condition, the degree of importance of the floor beams is approximately 0.74 at the point of strongest support, denoted by the peak (membership value = 1) in Figure 6.2. The degree of importance of the floor beams in good condition at the point of strongest support is approximately 0.54 as shown in Figure 6.3. It can be seen that each degree of importance on the horizontal axis has a different degree of support of a given subcomponent depending on its condition.

The mean values of the various importance factors are tabulated in Tables 6.1 through 6.3. These tables are presented for the purpose of showing

Figure 6.1 Membership Function for Floor Beam in Poor Condition

Figure 6.2 Membership Function for Floor Beam in Fair Condition

Figure 6.3 Membership Function for Floor Beam in Good Condition

Table 6.1 Mean Values of the Structural Importance for Bridge Deck Elements for Various Condition Classifications.

DECK ITEMS	STRUCTURAL IMPORTANCE				
	Condition Classifications				
	[v.poor] 0-1	[poor] 2-3	[fair] 4-5	[good] 6-7	[v.good] 8-9
1. Wearing-Surface	.51	.45	.33	.23	.17
2. Deck-Condition	.81	.77	.72	.50	.42
3. Curbs	.25	.20	.14	.10	.08
4. Median	.24	.21	.14	.11	.09
5. Sidewalks	.40	.33	.25	.17	.14
6. Parapets	.39	.33	.26	.19	.19
7. Railings	.41	.35	.26	.19	.16
8. Paint	.35	.31	.24	.18	.15
9. Drains	.51	.45	.35	.29	.22
10. Lighting	.29	.27	.20	.16	.15
11. Utilities	.25	.23	.17	.13	.11
12. Joint-Leakage	.54	.49	.41	.34	.28
13. Expansion-Joints	.62	.55	.47	.38	.30

Table 6.2 Mean Values of the Structural Importance for Bridge
Superstructure Elements for Various Condition Classifications

SUPERSTRUCTURE ITEMS	STRUCTURAL IMPORTANCE				
	Condition Classifications				
	[v.poor] 0-1	[poor] 2-3	[fair] 4-5	[good] 6-7	[v.good] 8-9
1. Bearing Devices	.79	.71	.60	.47	.42
2. Stringers	.79	.72	.61	.50	.44
3. Girders	.92	.85	.75	.64	.58
4. Floor Beams	.90	.83	.72	.60	.54
5. Trusses	.84	.77	.67	.56	.51
6. Paint	.49	.43	.35	.29	.24
7. Machinery	.70	.66	.58	.52	.44
8. Rivets or Bolts	.78	.71	.61	.49	.42
9. Welds - Cracks	.87	.83	.73	.63	.56
10. Rust	.74	.64	.54	.40	.31
11. Timber Decay	.83	.75	.65	.51	.43
12. Concrete-Cracking	.78	.70	.59	.49	.40
13. Collision Damage	.71	.64	.53	.42	.35
14. Deflection	.73	.66	.59	.50	.43
15. Alignment of Members	.71	.64	.54	.44	.37
16. Vibrations	.69	.63	.54	.43	.36

Table 6.3 Mean Values of the Structural Importance for Bridge Substructure Elements for Various Condition Classifications

SUBSTRUCTURE ITEMS	STRUCTURAL IMPORTANCE				
	Condition Classifications				
	[v.poor] 0-1	[poor] 2-3	[fair] 4-5	[good] 6-7	[v.good] 8-9
1. Bridge Seats	.76	.68	.57	.45	.40
2. Wings	.58	.51	.41	.33	.29
3. Backwall	.66	.58	.48	.40	.35
4. Footings	.74	.67	.57	.46	.42
5. Piles	.72	.66	.56	.46	.39
6. Erosion	.68	.60	.51	.40	.35
7. Settlements	.79	.70	.60	.50	.45
8. Piers-Caps	.73	.65	.56	.46	.41
9. Piers-Column	.78	.70	.60	.49	.43
10. Piers-Footing	.74	.67	.57	.47	.42
11. Piers-Piles	.74	.68	.59	.48	.42
12. Piers-Scour	.73	.65	.53	.43	.38
13. Piers-Settlement	.78	.70	.62	.51	.45
14. Pile-Bents	.75	.67	.58	.48	.42
15. Concrete-Cracking	.70	.62	.51	.37	.32
16. Steel-Corrosion	.74	.66	.54	.43	.36
17. Timber-Decay	.82	.72	.62	.50	.44
18. Debris-Seats	.46	.40	.33	.25	.21
19. Paint	.48	.41	.34	.26	.22
20. Collision-Damage	.68	.59	.48	.34	.28

that the mean value of the importance of a subcomponent increases as the physical condition deteriorates. It should also be noted that the mean value of the degree of importance does not coincide with the degree of importance with strongest support ($\mu = 1$). This is because the mean value is probabilistic in nature whereas the degree of support is fuzzy in nature.

The mean value cannot describe the importance factors adequately because it does not account for the fuzziness due to the dispersion of responses of experts. In short, the mean value does not capture the spread of responses to a fuzzy quantity. The grade of membership of a membership function, on the other hand, reflects the strength of each element in the fuzzy rating category as perceived by experts. The fuzziness in each importance factor is fully captured by having different degrees of support for different degrees of importance.

6.3.3 Fuzzy Rating Variables - Fuzzy Numbers

Bridge inspectors have been using the present Federal Condition Inspection rating scheme to record the condition of a bridge in the field since 1978 [FHWA 1979]. Existing condition databases are recorded using this scheme. Thus, this scheme was selected for the present study to provide a common measure of bridge condition.

Each numerical condition rating ranging from 0 to 9 has a linguistic description as defined in the National Bridge Inspection Standards [FHWA 1979]. For example, a numerical rating of 3 corresponds to "poor condition" and a rating of 6 corresponds to "fair condition". The use of numerical ratings instead of linguistic ratings presumably has the advantage of ease in recording the condition ratings in the field. The disadvantage of using a numerical rating is that the bridge inspector must memorize and understand

the linguistic definition of each numerical rating, and this may pose a problem for "new" inspectors.

In fact, it has been suggested that the use of linguistic rating (natural language) instead of numerical rating will yield a higher degree of rating consistency in the long run [Schmucker 1984]. Nevertheless, if a bridge inspector has a clear understanding of the meaning of each numerical rating, there should be little difference as to which method is selected.

Each numerical rating in the Federal rating scheme adopted for the present study has a meaningful but imprecise linguistic definition as shown in Table 6.4. For example, a numerical rating of "7" corresponds linguistically to "generally good condition". The expression "generally good" is meaningful but imprecise. Hence, the theory of fuzzy sets is also employed to capture the meaning of this imprecise expression.

Each linguistic rating expression can be represented by primary terms and hedges as shown in Table 6.4. Such representation is consistent with the fuzzy logic concepts. Each primary term is a fuzzy set by itself and can be represented by any convenient numerical grade such as between 0 and 1.0, where numbers leaning towards 0 and towards 1.0 correspond to "critical condition" and "excellent condition", respectively. The membership functions that characterize these fuzzy sets may be determined using any of the methods for constructing membership functions described in Chapter 5. The membership functions defining the above primary terms are shown in Figure 6.4.

The hedges, as described in Chapter 5, are not themselves modeled by fuzzy sets but rather are modeled as operators on the fuzzy restriction (membership function) that represents the primary terms. The hedges presented

Table 6.4 Relationship Between Numerical Ratings and Linguistic Expressions.

Numerical Rating	Linguistic Expression	Hedge	Primary Terms
0	Very Critical	Very	Critical
1	Critical	----	Critical
2	Very Poor	Very	Poor
3	Poor	----	Poor
4	Marginally Fair	Marginally	Fair
5	Generally Fair	Generally	Fair
6	Fair	----	Fair
7	Generally Good	Generally	Good
8	Good	----	Good
9	Very Good (New)	Very	Good

Figure 6.4 Membership Function for Rating Variables

in Table 6.4 have been defined in the literature as follows [Yager et al. 1987]:

Let X be any primary term

Then,

$$\text{VERY } X = \text{CON}(X)$$

$$\text{RATHER } X = \text{NORM}(\text{INT}(\text{CON}(X) \text{ AND } (\text{NOT CON}(X))))$$

$$\text{GENERALLY } X = \text{NORM}(\text{INT}(\text{DIL}(X)) \text{ AND } \text{INT}(\text{NOT DIL}(X)))$$

It should be emphasized that the foregoing definitions are subjective and tentative in nature.

Alternatively, each numerical rating can also be represented as a fuzzy set called a fuzzy number. A fuzzy number can be represented by a fuzzy set defined on the real line, x , with membership function $\mu_i(x)$ as the degree of belongingness of the element i in the fuzzy set [Dubois and Prade 1980].

Theoretically, if modeled correctly, both methods of representing the numerical condition rating scheme should yield essentially similar results. In other words, the final result is generally insensitive to the method of representing the linguistic rating expressions because the hedged primary terms and the fuzzy numbers, if modeled correctly, should essentially have identical membership functions. However, modeling the hedges as operators on the primary terms such that they reflect the normal meanings of the linguistic expression they represent is not an easy task. It is essentially a two-step process: first, the membership functions of the primary terms are constructed; second, the hedges are defined such that when operated on the primary terms they will yield fuzzy sets which reflect the meanings of the linguistic expressions. On the other hand, representing each numerical rating

as a fuzzy set is a simpler task because it involves the usual method of constructing membership functions.

Consequently, in the present work, the numerical ratings are represented as fuzzy numbers rather than primary terms and hedges. The membership functions of the various rating expressions proposed for the present study are presented in Table 6.5. These membership functions can be modified as better information is made available.

6.4 Fuzzy Model

6.4.1 Modeling Techniques

Two distinct inference methods are available to combine fuzzy knowledge in the literature. They are generally called the weighted fuzzy union and fuzzy weighted average [Mullarkey and Fenves 1985; Juang and Elton 1986].

If the importance factors are viewed as fuzzy modifiers, then the weighted fuzzy union would be an appropriate inference method. The fuzzy modifier is a fuzzy logic operation which may be used to change the characteristic function by spreading out the transition between full membership and nonmembership, by sharpening the transition, or by moving the position of the transition region. The weighted fuzzy union has the following mathematical form:

$$\bar{R} = U \left\{ \sum_{i=1}^n W_i \cdot R_i \right\}$$

where W_i denotes the non-fuzzy importance factor and R_i denotes the fuzzy rating of the i th subcomponent and $\bar{R}$ is the resulting fuzzy set denoting the overall condition of the component. The fuzzy modifiers are

Table 6.5 Numerical Ratings Expressed as Fuzzy Numbers

Numerical Rating	Descriptive Condition Rating	Fuzzy Numbers
0	Very Critical	[1.0 1 0.0 2]
1	Critical	[0.0 0 1.0 1 0.0 2]
2	Very Poor	[0.0 1 1.0 2 0.0 3]
3	Poor	[0.0 2 1.0 3 0.0 4]
4	Marginally Fair	[0.0 3 1.0 4 0.0 5]
5	Generally Fair	[0.0 4 1.0 5 0.0 6]
6	Fair	[0.0 5 1.0 6 0.0 7]
7	Generally Good	[0.0 6 1.0 7 0.0 8]
8	Good	[0.0 7 1.0 8 0.0 9]
9	Very Good (New)	[0.0 8 1.0 9]

simply the mean values of the importance factors presented in Tables 6.1 through 6.3. This knowledge combination approach is similar to the one presented by Elms [1984] for multiple criterion decision making with respect to building codes.

If the importance factors are viewed as independent fuzzy sets, then the fuzzy weighted average would be an appropriate inference method. This method can be envisioned as a union of intersections. The weighted average idea has been adopted in many studies of knowledge combination. Some instances where this method was used include computer security and risk analysis [Schmucker 1984] estimation of earthquake intensity based on building damage records [Juang and Elton 1986] and geotechnical knowledge-based system [Mullarkey and Fenves 1985]. As shown earlier, the fuzzy weighted average has a simple mathematical form:

$$\bar{R} = \frac{1}{\sum_i W_i} * \sum \{ W_i * R_i \}$$

where $\bar{R}$ is a fuzzy number denoting the component's resultant rating, R_i denotes the fuzzy rating of the i th subcomponent and W_i denotes the fuzzy importance factor for the i th subcomponent.

As mentioned earlier, the importance factors are imprecise quantities and can be best represented as fuzzy sets. The fuzziness and human uncertainty in this factor are captured by allowing different degrees of support for different degrees of importance. Clearly, any attempt to find a precise estimate of this imprecise factor will involve further approximation. Viewed in this perspective, it is believed that the fuzzy weighted average is clearly the most appropriate inference method for the present work.

There are essential two widely used methods for computing fuzzy weighted average. The first method employs the Zadeh's extension principle to extend the ordinary algebraic operations to fuzzy algebraic operations. For the sake of convenience, this method shall be called the "Direct Method" in the present work. The second method, which is a more efficient method for performing the fuzzy algebraic operations, is called the "Indirect Method" in the present work. The indirect method makes use of the α -cut representations of fuzzy sets and performs the extended algebraic operations by manipulating the fuzzy intervals at each α -cut. Both the direct method and indirect method will be discussed next.

6.4.2 Existing Computational Algorithms

6.4.2.1 The Direct Method

This method has been implemented in many decision-making analyses and studies of knowledge combination. It involves a direct extension of ordinary algebraic operations to fuzzy algebraic operations. The summation, multiplication, and division in this method involve fuzzy arithmetic based on Zadeh's extension principle .

Let

$$\begin{aligned} A &= [\mu_A(x)|x], & x \in U_1 \\ B &= [\mu_B(y)|y], & y \in U_2 \end{aligned}$$

Using the extension principle, the definition of fuzzy addition ($A + B$), fuzzy multiplication ($A * B$) and fuzzy division ($A \div B$) are as follows:

$$\begin{aligned} A + B &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x + y], x \in A, y \in B \} \\ A * B &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x * y], x \in A, y \in B \} \\ A \div B &= \text{Sup} \{ \min [\mu_A(x), \mu_B(y)] | [x \div y], x \in A, y \in B \} \end{aligned}$$

The resultant fuzzy set is mapped back to the desired rating expression using the Euclidean distance. This process involves the determination of the distance of a resultant fuzzy set to each of the fuzzy sets representing each of the possible rating expressions. As an example, suppose R is the resultant fuzzy set for which we are to find a natural language approximation, and "Poor" is a linguistic rating variable described by a fuzzy set denoted by P . Then, the "distance" between R and P denoted by D can be calculated using the following equation:

$$\begin{aligned} R &= [r(i)|i] \quad i \in U \\ P &= [p(i)|i] \quad i \in U \end{aligned}$$

$$D = [\sum_i^n \{r(i) - p(i)\}^2]^{\frac{1}{2}}$$

where i is an element in the universe U , and $r(i)$ and $p(i)$ denote the membership values for the i th element of the fuzzy sets R and P , respectively. An example illustrating this method is presented in Chapter 7.

6.4.2.2 The Indirect Method

The indirect method is based on the α -cut concept and interval analysis. This technique works with the membership value domains of linguistic variables instead of variable domains themselves (Dong and Wong 1987). This is a relatively new approach and is also known as the vertex method. The main advantage of this simpler algorithm over the direct method is that less computational effort is required. The indirect method can be summarized as a series of simple steps:

1. Select any α -cut value.
2. Find the elements corresponding to the α -cuts for each fuzzy set involved.
3. Perform the interval operations.

4. Repeat the above steps for different α -cut.
5. Construct the resultant fuzzy sets.

Recall that in Chapter 5 the α -cut of a fuzzy set A (A_α) was defined as all elements of the fuzzy set whose degrees of membership are greater than or equal to α , $0 < \alpha \leq 1$.

$$A_\alpha = \{ \mu_A(x) \geq \alpha : x \in X \}$$

The membership function of a fuzzy set A expressed in terms of the characteristic function $\mu_{A_\alpha}(x)$ of its α -level is:

$$\mu_A(x) = \sup_{\alpha} \min(\alpha, \mu_{A_\alpha}(x))$$

where

$$0 < \alpha \leq 1$$

and

$$\mu_{A_\alpha}(x) = \begin{cases} 1 & \text{if and only if } x \in A_\alpha \\ 0 & \text{otherwise} \end{cases}$$

A fuzzy set A may be decomposed into its level-sets through the resolution identity such that

$$A = \sum_{\alpha} \alpha A_\alpha$$

where αA_α is the product of a scalar α with the set A_α and $\sum$ denotes union of A_α , with α ranging from 0 to 1.

For example, a fuzzy set A may be represented as

$$A = [0.1|1, 0.3|2, 0.5|6, 0.9|7, 1|9]$$

or

$$A = [0.1|1+0.3|2+0.5|6+0.9|7+1|9]$$

where $+$ means union. A can be rewritten as

$$\begin{aligned} A = & 0.1[1|1+1|2+1|6+1|7+1|9] + \\ & 0.3[1|2+1|6+1|7+1|9] + \\ & 0.5[1|6+1|7+1|9] + \\ & 0.9[1|7+1|9] + \\ & 1.0[1|9] \end{aligned}$$

Thus, $A_{\alpha=0.1} = [1, 2, 6, 7, 9]$
 $A_{\alpha=0.3} = [2, 6, 7, 9]$
 $A_{\alpha=0.5} = [6, 7, 9]$
 $A_{\alpha=0.9} = [7, 9]$
 $A_{\alpha=1.0} = [9]$.

The intermediate elements of each alpha sets, e.g. 2, 6, 7 of $A_{\alpha=0.1}$, may be ignored. Thus,

$A_{\alpha=0.1} = [1, 9]$
 $A_{\alpha=0.3} = [2, 9]$
 $A_{\alpha=0.5} = [6, 9]$
 $A_{\alpha=0.9} = [7, 9]$
 $A_{\alpha=1.0} = [9]$.

The upper and lower limits of each alpha sets define an interval number.

Using this concept, the resultant fuzzy set of the fuzzy inference model can be defined by the interval numbers of a series of alpha cuts. For a given alpha cut, the upper and lower alpha level values of each fuzzy rating and fuzzy importance coefficient are obtained. These alpha values are then manipulated according to the proposed fuzzy inference equation. The resulting maximum and minimum values from this fuzzy operation are then selected.

Since this method is computationally more efficient, it is employed in the present work. An example illustrating this method is also presented in Chapter 7.

6.5 Concluding Remarks

The procedure for rating an existing bridge structure requires a careful evaluation of many complex and often conflicting factors. Consequently, personal judgment, experience and intuition are frequently required for proper evaluation of the bridge condition. It was found that personal judgment and experience are related to the assessment of the importance of each

subcomponent. The importance factor was found to depend upon the physical condition of the subcomponent. The importance factors were evaluated by means of an opinion survey of bridge inspectors and engineers.

The overall condition of a component is assessed on the basis of condition ratings and importance factors of various bridge subcomponents. It was decided that condition ratings and importance factors are best represented by fuzzy sets since the dispersion of expert opinions could be included in the analysis. The fuzzy weight average method, using the indirect method, was selected to combine condition ratings and importance factors for the bridge condition model.

CHAPTER 7

7.0 NUMERICAL EXAMPLES

7.1 Introduction

As mentioned in Chapter 6, the assessment and subsequent designation of a rating value to each bridge subcomponent is presently performed according to guidelines established by the National Bridge Inspection Standards (NBIS). However, engineering judgment and the subjective wisdom of bridge inspectors are still necessary even with these guidelines. The development of a method that can limit this human subjectivity and promote standardization during bridge inspection will indeed be useful.

Since conditions of various subcomponents by themselves are of no practical use, they must be combined to yield the overall component rating. However, there is as yet no established approach for the bridge inspector to perform this step. Thus, the emphasis in the present work is to develop a mechanism whereby the overall component condition rating can be inferred from various subcomponent condition ratings. In the present study this inference mechanism was developed based on information obtained through interviews with bridge inspectors. The rating of a subcomponent condition is not a measure of the importance of the subcomponent but rather a measure of the extent of deterioration of that subcomponent. Thus, the overall component rating is not simply the minimum value of all subcomponent ratings but a function of the importance and deterioration of each subcomponent.

Three examples are presented in the following section to demonstrate the proposed technique in detail. Analyses are also performed to examine the

accuracy of the results from the proposed inference model with available bridge assessment records.

7.2 Illustrative Examples

The objective of the numerical examples presented herein is two-fold: first, to demonstrate the use of fuzzy weighted average arithmetic, and second, to demonstrate the feasibility of this approach for combining bridge inspection ratings and their associated importance.

7.2.1 Example 1

The first two steps of the fuzzy rating algorithm involve the translation of rating variables to discrete fuzzy sets. For the purpose of illustration and simplicity, only three rating variables are considered in this example. It is further assumed that the rating values are variables whose values are natural language expressions. The three natural language expressions selected to represent the rating variables are "Good", "Fair" and "Poor". These natural expressions are then, in turn, names for fuzzy sets composed of numerical values. In this example, the fuzzy sets representing the rating variables are assumed to be defined as follows:

<u>Rating</u>	<u>Fuzzy Sets</u>
Good	= { 0 1, 0 2, 0 3, 0.5 4, 1 5 }
Fair	= { 0 1, 0 2, 1 3, 0.5 4, 0 5 }
Poor	= { 0 1, 1 2, 0 3, 0 4, 0 5 }

The fuzzy sets are of the following form:

$$Y = \{m(x)|x\}$$

where $m(x)$ denotes the degree of membership of x , and x defines the bridge condition universe of the fuzzy sets. The universe of the above fuzzy sets

representing the fuzzy ratings is denoted by a set of five integers { 1, 2, 3, 4, 5 }. The use of more elements in the universe will result in a better representation of the quantity of interest, but it will also involve more arithmetic manipulations in the computation. The foregoing fuzzy sets can be depicted graphically as shown in Figure 7.1.

For the purpose of illustration, it is further assumed in this example that the condition rating for the bridge superstructure under investigation is controlled by three factors only: stringers, floor beams, and girders. It is assumed that during the bridge inspection the stringers were all found to be in "good" condition; floor beams in "fair" condition; and girders in "poor" condition. Moreover, the fuzzy sets for structural importance of the three bridge elements that are associated with the given condition assessments are given as follows:

<u>Elements</u>	<u>Structural Importance</u>
Stringers	{ 0 1, 1 2, 0.5 3, 0 4 }
Floor Beams	{ 0 1, 0 2, 0.5 3, 1 4 }
Girders	{ 0 1, 0 2, 1.0 3, 0 4 }

In general, the elements in the universe of a fuzzy set can be real numbers or integers. However, for the ease of representation, the universe of the above fuzzy sets representing the structural importance factors is denoted by a set of four integers { 1, 2, 3, 4 } with 1 being insignificant and 4 being very significant. Also, the choice of the number of elements in the fuzzy sets is arbitrary.

The translation of linguistic terms into fuzzy sets is usually performed using either a dictionary established by experts or sufficient information gathered through scientific research. The dictionary is a representation of the knowledge and opinions of experts and scientists.

MEMBERSHIP FUNCTION - BRIDGE CONDITION (Example Problem)

Figure 7.1 Membership Function for Condition Ratings in Example Problem 1.

The third step of the proposed algorithm involves the computation of the fuzzy set representing the entire system using fuzzy weighted average approach. The definitions for fuzzy addition, fuzzy multiplication, and fuzzy division are given in Chapter 6 and summarized as follows :

$$\begin{aligned}\text{Let } A &= \{a(i)|i; 1 \leq i \leq n\} \\ B &= \{b(j)|j; 1 \leq j \leq n\}\end{aligned}$$

where $a(i)$ and $b(j)$ are the degrees of membership for the i th and j th elements, respectively. Then

$$\begin{aligned}A+B &= \sup \{ \min(a(i), b(j)) | [i+j]; 1 \leq i, j \leq n \} \\ A*B &= \sup \{ \min(a(i), b(j)) | [i*j]; 1 \leq i, j \leq n \} \\ A/B &= \sup \{ \min(a(i), b(j)) | [i/j]; 1 \leq i, j \leq n \}\end{aligned}$$

Using the definitions given above for the fuzzy arithmetic operations, we can now perform the fuzzy weighted average of this example.

Let A, B and C be the fuzzy sets representing the structural importance for stringers, floor beams and girders, respectively. Let X, Y and Z be the fuzzy sets representing the linguistic ratings "good", "fair", and "poor" for the stringers, floor beams and girders, respectively.

The fuzzy weighted average rating in this example can be rewritten as follows:

$$R = \frac{(X*A) + (Y*B) + (Z*C)}{(A+B+C)}$$

where A, B, C, X, Y and Z are the fuzzy sets described earlier.

We calculate

$$\begin{aligned}(A+B) &= \max \{ \min(0,0) | [1+1] \\ &\quad \max \{ \min(0,0) | [1+2], \min(1,0) | [2+1] \} \\ &\quad \max \{ \min(0,0.5) | [1+3], \min(1,0) | [2+2], \min(0.5,0) | [3+1] \} \end{aligned}$$

$$\begin{aligned}
& \max \{ \min(0,1) \mid [1+4], \min(1,0.5) \mid [2+3], \min(0.5,1) \mid \min[3+2] \\
& \quad \min(0,0) \mid [4+1] \} \\
& \max \{ \min(1,1) \mid [2+4], \min(0,0) \mid [4+2], \min(0.5,0.5) \mid [3+3] \} \\
& \max \{ \min(0.5,1) \mid [3+4], \min(0,0.5) \mid [4+3] \} \\
& \max \{ \min(0,1) \mid [4,4] \} \\
& = \{ 0 \mid 2, 0 \mid 3, 0 \mid 4, 0.5 \mid 5, 1 \mid 6, 0.5 \mid 7, 0 \mid 8 \}
\end{aligned}$$

Similarly,

$$\begin{aligned}
(A+B+C) &= \{ 0 \mid 1, 0 \mid 2, 0 \mid 3, 0 \mid 4, 0 \mid 5, 0 \mid 6, 0 \mid 7, 0.5 \mid 8, 1 \mid 9, 0.5 \mid 10, 0 \mid 11, 0 \mid 12 \} \\
(X*A) &= \max \{ \min(0,0) \mid [1*1] \} \\
& \max \{ \min(0,1) \mid [1*2], \min(0,0) \mid [2*1] \} \\
& \max \{ \min(0,0.5) \mid [1*3], \min(0,0) \mid [3*1] \} \\
& \max \{ \min(0,0) \mid [1*4], \min(1,0) \mid [4*1] \} \\
& \max \{ \min(0,1) \mid [2*2] \} \\
& \max \{ \min(0,0.5) \mid [2*3], \min(0,1) \mid [3*2] \} \\
& \max \{ \min(0,0) \mid [2*4], \min(0.5,1) \mid [4*2] \} \\
& \max \{ \min(0,0.5) \mid [3*3] \} \\
& \max \{ \min(0,0) \mid [3*4], \min(0.5,0.5) \mid [4*3] \} \\
& \max \{ \min(0.5,0) \mid [4*4] \} \\
& \max \{ \min(1,0) \mid [5*1] \} \\
& \max \{ \min(1,1) \mid [5*2] \} \\
& \max \{ \min(1,0.5) \mid [5*3] \} \\
& \max \{ \min(1,0) \mid [5*4] \} \\
& = \{ 0 \mid 1, 0 \mid 2, 0 \mid 3, 0 \mid 4, 0 \mid 5, 0 \mid 6, 0.5 \mid 8, 0 \mid 9, 1 \mid 10, 0.5 \mid 12, 0.5 \mid 15 \\
& \quad 0 \mid 16, 0 \mid 20 \}
\end{aligned}$$

Since this is not a convex set, we will adjust the values to maintain convexity. Convexity adjustment replaces multiple peaks in a fuzzy set with a single peak. Thus,

$$(X*A) = \{ 0 \mid 1, 0 \mid 2, 0 \mid 3, 0 \mid 4, 0 \mid 5, 0 \mid 6, 0 \mid 7, 0.5 \mid 8, 0.75 \mid 9, 1 \mid 10, 0.75 \mid 11, 0.5 \mid 12, 0.5 \mid 13, 0.5 \mid 14, 0.5 \mid 15, 0 \mid 16, 0 \mid 17, 0 \mid 18, 0 \mid 19, 0 \mid 20 \}$$

Similarly,

$$\begin{aligned}
(Y*B) &= \{ 0 \mid 1, 0 \mid 2, 0 \mid 3, 0 \mid 4, 0 \mid 5, 0 \mid 6, 0 \mid 7, 0 \mid 8, 0.5 \mid 9, 0.67 \mid 10, 0.83 \mid 11, 1 \mid 12 \\
& \quad 0.88 \mid 13, 0.75 \mid 14, 0.63 \mid 15, 0.5 \mid 16, 0 \mid 17, 0 \mid 18, 0 \mid 19, 0 \mid 20 \} \\
(Z*C) &= \{ 0 \mid 1, 0 \mid 2, 0 \mid 3, 0 \mid 4, 0 \mid 5, 1 \mid 6, 0 \mid 7, 0 \mid 8, 0 \mid 9, 0 \mid 10, 0 \mid 11, 0 \mid 12, 0 \mid 13, \\
& \quad 0 \mid 14, 0 \mid 15, 0 \mid 16, 0 \mid 17, 0 \mid 18, 0 \mid 19, 0 \mid 20 \}
\end{aligned}$$

Hence,

$$(X*A)+(Y*B)+(Z*C) =$$

$$\begin{aligned} &0|1, \dots 0|22, 0.5|23, 0.5|24, 0.67|25, 0.75|26, 0.83|27, 1|28, 0.88|29, \\ &0.75|30, 0.75|31, 0.63|32, 0.5|33, 0.5|34, 0.5|35, 0.5|36, 0.5|37, \\ &0|38, \dots 0|60 \end{aligned}$$

where denotes zero membership values for the elements in between.

Finally, $\frac{(X*A)+(Y*B)+(Z*C)}{(A+B+C)}$ using the division rule yields

$$\{0|1, 0|2, 1|3, 0.6|4, 0|5\}$$

The adjustment that is normally made to the resulting fuzzy set is to insure its convexity. Keeping all fuzzy sets convex makes the task of finding a natural language expression to describe a computed fuzzy set easier. The other adjustment that is often made to a fuzzy set is the normalization operation. Normalization insures that at least one element of the set has a degree of membership of one. It should be noted that there is no apparent mathematical rationale supporting the use of convexity and normalization operations on the fuzzy sets produced by each intermediate calculation. However, empirical tests have shown that enforcing normalization and convexity produced final translated results that are more accurate (Mullarky 1985).

The last step of this algorithm is to map the resultant fuzzy set of the entire system back to a rating variable. In this example, the above fuzzy set can be mapped back to one of the natural language rating expressions in the rating language "good", "fair" or "poor". The mapping of a fuzzy set to a natural language expression is a process involving the determination of the distance of a given fuzzy set to each of the fuzzy sets representing a possible natural language expression. As an example, if R is the resultant fuzzy set for which we are to find a natural language approximation, and "Poor" is

a fuzzy set denoted by P and represents one of the linguistic variables in the rating language, then the "distance" between R and P, denoted by $\delta(R,P)$ can be calculated as follows:

Let

$$\begin{aligned} R &= \{r(i)|i; 1 \leq i \leq n\} \\ P &= \{p(i)|i; 1 \leq i \leq n\} \end{aligned}$$

Then

$$\delta(R,P) = \left(\sum_i^n \{r(i) - p(i)\}^2 \right)^{\frac{1}{2}}$$

where i is an element in the universe.

This calculation will be repeated for all the natural language expressions. The natural language rating expression associated with the shortest distance from R in the above calculation is taken as its natural language equivalent.

In the example,

$$\begin{aligned} \delta(R,X) &= 1.4177 \\ \delta(R,Y) &= 0.1000 \\ \delta(R,Z) &= 1.5362 \end{aligned}$$

where, R denotes the resultant fuzzy set, and X, Y and Z are the fuzzy sets representing the "good", "fair", and "poor" bridge condition ratings of this example, respectively. Since, the distance between R and Y is the shortest, it can be concluded that for the above example the bridge superstructure has a "fair" overall condition rating.

A computer program for the above algorithm has been written and compiled with Microsoft Fortran 4.0 for the present study. Typical run time for a full

scale model, when run on a Zenith Computer (an IBM PC compatible machine) operating at 8 M Hz with a math co-processor and 640 K random access memory (RAM), ranges from a few minutes to half an hour, depending on the complexity of the problem.

7.2.2 Example 2

The purpose of this example is to demonstrate a solution technique for the fuzzy inference equation described earlier from a different perspective. This solution technique is based on the α -cut concept presented in Chapter 6. In this example, the condition of a bridge element is represented by a fuzzy number instead of a linguistic variable.

The current condition rating is reported using a numerical scale between 0 and 9. Because bridge inspection is a highly imprecise process, each rating value is indeed a fuzzy number. For example, when a bridge inspector records the condition of a bridge element using the 0 to 9 scale as 5, it should be interpreted that the condition of the bridge element is "about 5" which is a fuzzy number. Thus a fuzzy number, I, is a fuzzy set with membership function $\mu_I(x)$ as the degree of belongingness of the element x in this set. For example, the fuzzy number "about 5" can be represented with the following L - R type membership function:

$$\mu_5(x) = \begin{cases} (x-3)/2 & 3 \leq x \leq 5 \\ (7-x)/2 & 5 < x \leq 7 \\ 0 & \text{otherwise} \end{cases}$$

For the purpose of illustration, it is assumed in this example that the condition rating of a bridge superstructure under investigation is controlled by the floor beams and main girders. It is further assumed that the condition

of the floor beams and main girders are "about 3" and "about 7" on the 0-9 scale described earlier.

In this example, the grades of membership for the fuzzy number, denoted by I, are assumed to be defined as follows:

For I=3

$$\mu_{I=3}(r1) = \begin{cases} r1 - 2 & 2 \leq r1 \leq 3 \\ 4 - r1 & 3 < r1 \leq 4 \\ 0 & \text{otherwise} \end{cases}$$

For I=7

$$\mu_{I=7}(r2) = \begin{cases} r2 - 6 & 6 \leq r2 \leq 7 \\ 8 - r2 & 7 < r2 \leq 8 \\ 0 & \text{otherwise} \end{cases}$$

The grades of membership for the fuzzy importance coefficient, denoted by W, of the floor beams and girders associated with the fuzzy number "about 3" and "about 7" are, respectively, assumed to be defined as follows:

For $W_{I=3}$

$$\mu_W(w1) = \begin{cases} (w1 - 0.5)/0.4 & 0.5 \leq w1 \leq 0.9 \\ (1.0 - w1)/0.1 & 0.9 < w1 \leq 1.0 \\ 0 & \text{otherwise} \end{cases}$$

For $W_{I=7}$

$$\mu_W(w2) = \begin{cases} (w2 - 0.3)/0.2 & 0.3 \leq w2 \leq 0.5 \\ (0.8 - w2)/0.3 & 0.5 < w2 \leq 0.8 \\ 0 & \text{otherwise} \end{cases}$$

The shape of the above fuzzy sets are depicted graphically as shown in Figure 7.2.

Figure 7.2 Resultant Fuzzy Rating Using the Indirect Method.

In this example, the resultant fuzzy set, $\bar{R}$, is computed using three alpha cuts, i.e. at $\alpha=0.0$, $\alpha=0.5$, $\alpha=1.0$. Of course, more alpha cuts would yield a more refined resultant fuzzy set. The upper and lower limits for the fuzzy ratings, $R1$ and $R2$, and their respective importance coefficients, $W1$ and $W2$, at the three alpha cuts shown in Figure 7.2 are as follows:

$\alpha = 0$	$R1=[2,4]$ $R2=[6,8]$ $W1=[0.5,1.0]$ $W2=[0.3,0.8]$
$\alpha = 0.5$	$R1=[2.5,3.5]$ $R2=[6.5,7.5]$ $W1=[0.7,0.95]$ $W2=[0.4,0.65]$
$\alpha = 1.0$	$R1=[3]$ $R2=[7]$ $W1=[0.9]$ $W2=[0.5]$

The upper and lower limits of the resultant set, $\bar{R}$, at the various α levels are computed as follows:

$$\bar{R}_\alpha = \frac{1}{\sum_{i=1} W_{i\alpha}} * \sum_{i=1} \{ W_{i\alpha} * R_{i\alpha} \}$$

A summary of the results are presented in Table 7.1. At $\alpha=0.0$, the lower and upper limits of the resultant interval, $\bar{R}$, are 2.9 and 6.5, respectively. At $\alpha=0.5$, the upper and lower limits of the resultant interval are 3.7 and 5.4, respectively. At $\alpha=1.0$, the resultant interval in this case is reduced to a point whose value is 4.4. The shape of the resultant fuzzy set is shown in Figure 7.2. The main advantage of this indirect approach over the direct approach presented in Example 1 is the reduced amount of computa-

Table 7.1 Resultant Rating Limits for the Various Alpha-Cuts

α -cut Levels	R1	R2	W1	W2	$\bar{R}$	Selection
0.0	2	6	0.5	0.3	3.50	
	4				4.75	
	2	8			4.25	
	4				5.50	
	2	6	1.0		2.92	<==
	4				4.46	
	2	8			3.38	
	4				4.92	
	2	6	0.5	0.8	4.46	
	4				5.23	
	2	8			5.67	
	4				6.46	<==
	2	6	1.0		3.77	
	4				4.88	
	2	8			4.66	
	4				5.77	
0.5	2.5	6.5	0.7	0.4	3.95	
	3.5				4.59	
	2.5	7.5			4.32	
	3.5				4.95	
	2.5	6.5	0.95		3.69	<==
	3.5				4.39	
	2.5	7.5			3.98	
	3.5				4.69	
	2.5	6.5	0.7	0.65	4.43	
	3.5				4.59	
	2.5	7.5			4.94	
	3.5				4.91	
	2.5	6.5	0.95		5.43	<==
	3.5				4.13	
	2.5	7.5			4.72	
	3.5				5.13	
1.0	3	7	0.9	0.5	4.42	* <==

$\bar{R}$ Resultant fuzzy rating limits

* At $\alpha = 1.0$, the result is not an interval but a point.

| Repetition of the value above this symbol

tional effort required. This is particularly true if only a few alpha levels are needed to compute the resultant fuzzy set.

The mapping of the resultant fuzzy set back to one of the fuzzy numbers is quite similar to the approach employed in Example 1. Such mapping works with the membership value domains of the fuzzy variables instead of on the variable domains themselves. If R is the resultant fuzzy set for which we are to compute an equivalent fuzzy number, and N is a fuzzy set representing one of the fuzzy numbers, then the distance between R and N, denoted by δ , can be calculated as follows:

$$\begin{aligned} R &= \alpha [r_{\min}, r_{\max}]; & 0.0 \leq \alpha \leq 1.0 \\ N &= \alpha [n_{\min}, n_{\max}]; & 0.0 \leq \alpha \leq 1.0 \end{aligned}$$

$$\delta(R, N) = \left(\sum_{\alpha=0.0}^{1.0} (\{r_{\min} - n_{\min}\}^2 + \{r_{\max} - n_{\max}\}^2) \right)^{\frac{1}{2}}$$

In this example, it is obvious that the fuzzy number that most likely matches the resultant fuzzy set is either I=4 and I=5. The remaining fuzzy numbers may be neglected.

$$\begin{aligned} R_{\alpha=0.0} &= [2.92, 6.46] \\ R_{\alpha=0.5} &= [3.69, 5.43] \\ R_{\alpha=1.0} &= [4.42] \end{aligned}$$

$$\begin{aligned} N4_{\alpha=0.0} &= [3.0, 5.0] \\ N4_{\alpha=0.5} &= [3.5, 4.5] \\ N4_{\alpha=1.0} &= [4] \end{aligned}$$

$$\begin{aligned} N5_{\alpha=0.0} &= [4.0, 6.0] \\ N5_{\alpha=0.5} &= [4.5, 5.5] \\ N5_{\alpha=1.0} &= [5] \end{aligned}$$

and

$$\begin{aligned} \delta(R, N4) &= 1.79 \\ \delta(R, N5) &= 1.54 \end{aligned}$$

Since the distance between R and N5 is the shortest, the resultant rating is "about 5". For the sake of comparison, Example 1 was recalculated using the indirect approach. As expected, the result from this indirect method was found to be the same as from the direct method in Example 1.

7.2.3 Example 3

The present study is not concerned with how to assess the condition of the various subcomponents. However, for the sake of continuity and to establish the mathematical foundation for future research, an illustration of the proposed fuzzy logic approach for evaluating the condition of a subcomponent is presented in this example. Since there are many types of bridges with each having many subcomponents, the development of techniques for accurate condition assessment is an area which will require much future research. Furthermore, research in this area is hampered by the lack of detailed data and records that illustrate how the the rating of each subcomponent is determined.

In this example, an attempt is made to estimate the condition of a reinforced concrete stringer using a fuzzy logic approach. For simplicity, it is assumed herein that the condition of a reinforced concrete stringer is controlled by four types of imperfection: corrosion of the reinforcing steel and cracking, spalling and scaling of the concrete. The combined effect of these imperfections is difficult to assess objectively and consistently. However, with the development of fuzzy logic, there is now a method to handle this problem.

As an illustrative example to demonstrate the use of fuzzy logic as a potential tool in modeling the interaction between concrete quality and

corrosion, the following imperfections are assumed present in a reinforced concrete stringer:

Concrete Quality

Average crack width = 0.029 in.

Average scaling depth = 0.70 in.

Average spalling width = 9.50 in.

Steel Quality

Average degree of corrosion = 45%

For the purpose of illustration, assume the membership functions for concrete cracks, scaling and spalling and steel corrosion for the various deterioration levels are known and plotted in Figures 7.3 through 7.6. Methods of developing these membership functions have been presented elsewhere (Tee and Bowman 1986; Tee et al. 1988a)

The reinforced concrete stringer quality in this hypothetical example can be modeled based on a combination of the characteristics for the flaws. The method for combining the flaw evaluations is to examine a range in the characteristics that corresponds to either no interaction or complete interaction of the flaws. This fuzzy logic approach has been suggested for evaluating weld quality [Bowman 1985; Bowman and Yao 1983] and metal fatigue [Bowman et. al 1985].

Let A, B, C and D be the fuzzy sets representing cracks, scaling, spalling and corrosion, respectively. The effect of each imperfection acting separately is obtained by the union of fuzzy sets A, B, C and D, while the effect of all flaws acting jointly is given by the algebraic sum of A, B, C, and D. Thus, the grade of membership in a particular structural quality level, represented by fuzzy set E, can be evaluated as follows:

MEMBERSHIP FUNCTION - CRACKING

Figure 7.3 Structural Condition Membership Functions for Concrete Crackings.

Figure 7.4 Structural Condition Membership Functions for Concrete Scaling

Figure 7.5 Structural Condition Membership Functions for Concrete Spalling

Figure 7.6 Structural Condition Membership Functions for Reinforcing Steel Corrosion.

$$\mu_{AUBUCUD} < \mu_E < \mu_{A+B+C+D}$$

The limits in the above expression are given by:

$$\mu_{AUBUCUD} = \mu_A \cup \mu_B \cup \mu_C \cup \mu_D$$

$$\mu_{A+B+C+D} = \mu_A + \mu_B + \mu_C + \mu_D$$

where μ_A , μ_B , μ_C , μ_D , and μ_E are the grades of membership in fuzzy sets A, B, C, D and E, respectively.

By using the corrosion and concrete quality parameters in conjunction with the membership functions, the overall structural condition due to the combined effect of all parameters can be obtained. To illustrate this procedure consider the "very poor" structural condition. From Figure 7.3 it can be observed that a 0.70 membership grade for "very poor" structural condition is indicated for a 0.029 in. crack width. (Note that the same 0.029 in. crack width gives a 0.30 membership grade for "poor" structural condition and a 0.0 membership for "fair", "good" and "very good" structural condition). Proceeding in this fashion, the "very poor" condition can be evaluated for all of the imperfection severities as follows:

$$\mu_{VP}(A) = 0.70 \quad \text{for 0.029 in. cracking}$$

$$\mu_{VP}(B) = 0.00 \quad \text{for 0.70 in. scaling}$$

$$\mu_{VP}(C) = 0.50 \quad \text{for 9.50 in. spalling}$$

$$\mu_{VP}(D) = 0.50 \quad \text{for 45% corrosion}$$

Using these values, the "very poor" structural condition evaluation can be bounded as follows:

$$\begin{aligned} \mu_{AUBUCUD} &= \max [\mu_{VP}(A), \mu_{VP}(B), \mu_{VP}(C), \mu_{VP}(D)] \\ &= \max[0.7, 0, 0.5, 0.5] = 0.7 \end{aligned}$$

$$\begin{aligned}\mu_{A+B+C+D} &= 1 - (1-\mu_{VP}(A))(1-\mu_{VP}(B))(1-\mu_{VP}(C))(1-\mu_{VP}(D)) \\ &= 1 - (1-0.7)(1-0)(1-0.5)(1-0.5) = 0.925\end{aligned}$$

Consequently, the membership value for very poor structural condition classification falls in the range:

$$0.7 < \mu_{VP}(E) < 0.925$$

The lower and upper bound in this range can be viewed as the degree of "belief" that the overall structural condition is very poor when the effects of flaws are acting separately and when they are acting jointly, respectively.

The same procedure is repeated to define the upper and lower limits of other structural condition classifications. The grades of membership for fuzzy set A, B, C and D, and the upper and lower limits of fuzzy set E are shown in Table 7.2. The lower and upper membership limits in Table 7.2 can be depicted graphically as fuzzy intervals as shown in Figure 7.7. These intervals can be represented in the form of a modified histogram with unit cells as shown in the same figure. The resultant condition classification can thus be obtained by computing the first central moment of area of this histogram. Using this approach, the final condition assessment due to the combined effect of the various flaws is found to be closely associated with the "poor" classification.

A similar example can be constructed using numerical rating variables instead of linguistic expressions. The choice on the type of rating variables, whether numerical or linguistic, will not change the validity of the proposed fuzzy logic approach. If the numerical rating scheme is selected,

Table 7.2 Structural Condition Grades of Membership

Φ Rating	Membership Grade				Fuzzy Union	Fuzzy Algebraic Sum
	Cracks 0.029"	Scaling 0.70"	Spalling 9.5"	Corrosion 45%		
VERY GOOD	0	0	0	0	0	0
GOOD	0	0	0	0	0	0
FAIR	0	0.35	0	0	0.35	0.35
POOR	0.3	0.75	0.5	0.5	0.75	0.956
VERY POOR	0.7	0	0.5	0.5	0.7	0.925

Φ Structural Condition Rating Expressions.

Figure 7.7 Condition Classification Histogram.

then the membership function for the various flaws must be constructed for each numerical rating variable.

With the advent of the computer age, this approach can be implemented on a microcomputer. The bridge inspector will be prompted of the various flaws for each subcomponent and the computer will perform the computation automatically. For actual applications of this approach, further investigation is necessary. Specifically, various flaws for each subcomponent must be identified and membership functions for each flaw must be constructed.

7.3 Testing of Bridge Condition Inference Model

7.3.1 General Remarks

Computer programs for the present work have been developed using both the direct method as illustrated in Example 1 and indirect method as shown in Example 2. The technique for solving the proposed fuzzy inference equation using the direct method works with the variable domains while the indirect method works with the membership domains. In the literature, the direct method of solving the fuzzy inference equation is much more widely discussed and applied than the indirect method. This is probably because the direct solution technique is the older of the two methods. Although the direct method and the indirect method generally yield identical results, the direct method requires much more computer run time than the indirect method, especially when solving complex problems. Thus, the indirect method of solving the fuzzy inference equation is recommended for the present work and is used in investigating the accuracy of the proposed inference model using real inspection data.

7.3.2 Inspector Versus Computer Rating

The purpose of this section is to investigate the accuracy of the proposed fuzzy inference model with available bridge assessment histories. Previous bridge inspection records submitted by a number of experienced state bridge inspectors were examined and those records with individual elements having very different ratings were selected to test the proposed inspection model. Inspection records for six different bridges were selected for this analysis. Two support conditions and two basic bridge types are represented by the six bridges selected: simple and continuous spans for steel beam and reinforced concrete girder bridges.

The results of this investigation are presented in Tables 7.3 through 7.5. In general, it can be concluded that the condition assessments predicted by the proposed model are in good agreement with the assessments given by the bridge inspectors: slight variation of the results between actual inspector assessment and the norm as represented by the fuzzy inference model can be attributed to the following reasons:

1. Bridge inspectors sometimes tend to give a slightly more conservative estimate than the norm.
2. Importance coefficients obtained from the opinion survey via questionnaires may need further refinement.

The bridge component ratings shown in Tables 7.3 to 7.5 are fairly typical of rating reports for bridge components in Indiana. Moreover, it can be observed that rating values are not provided for all subcomponent items and that often little difference in the rating values exist for the subcomponents of a bridge component. However, when notable differences do occur, as they do for the deck subcomponent ratings of Bridges 1, 4 and 5, the proposed model still does an excellent job of predicting the inspector rating.

Table 7.3 Comparison of Overall Deck Ratings Given By Bridge Inspectors With Those Generated By Computer

DECK Elements	Type of Structure ^a					
	1.	2.	3.	4.	5.	6.
1. Wearing Surface	3	7	5	4	4	7
2. Deck-Structure	-	6	6	5	5	7
3. Curbs	7	7	6	6	6	8
4. Median	-	7	-	-	6	-
5. Sidewalks	7	7	-	6	7	7
6. Parapet	7	7	6	-	7	-
7. Railing	7	6	6	6	7	8
8. Paint	7	6	-	7	-	-
9. Drains	7	7	-	6	6	8
10. Lighting Standards	-	-	-	-	-	8
11. Utilities	-	-	-	-	-	-
12. Joint Leakage	6	7	5	5	6	7
13. Expansion Joints	6	7	5	5	7	7
Rating By Inspectors	5	7	5	5	5	7
Rating Model	5	7	5	5	6	7

a

1. Continuous Reinforced Concrete Girder
2. Steel Beam with Reinforced Concrete Approach
3. Reinforced Concrete Girder
4. Continuous Steel Beam
5. Continuous Reinforced Concrete Girder
6. Reinforced Concrete Girder

Table 7.4 Comparison of Superstructure Rating Given By Bridge Inspectors With Those Generated By Computer

SUPERSTRUCTURE Elements	Type of Structure ^a					
	1.	2.	3.	4.	5.	6.
1. Bearing Devices	-	6	6	7	7	-
2. Stringers	-	-	-	-	-	-
3. Girder, Beams	6	7	7	7	7	8
4. Floor Beams	-	-	-	-	-	-
5. Trusses - General	-	-	-	-	-	-
6. Paint	-	6	6	7	-	-
7. Machinery	-	-	-	-	-	-
8. Rivets or Bolts	-	7	-	7	-	-
9. Welds - Cracks	-	-	-	-	-	-
10. Rust	-	6	6	7	-	-
11. Timber Decay	-	-	-	-	-	-
12. Concrete Cracking	5	7	7	-	7	8
13. Collision Damage	7	7	7	-	-	-
14. Deflection - Load	7	7	7	7	7	8
15. Alignment	7	7	6	7	7	8
16. Vibrations	7	7	7	7	7	8
Rating By Inspectors	6	7	7	7	7	8
Rating Model	6	6	7	7	7	8

a

1. Continuous Reinforced Concrete Girder
2. Steel Beam with Reinforced Concrete Approach
3. Reinforced Concrete Girder
4. Continuous Steel Beam
5. Continuous Reinforced Concrete Girder]
6. Reinforced Concrete Girder

Table 7.5 Comparison of Substructure Ratings Given By Bridge Inspectors With Those Generated By Computer

SUBSTRUCTURE Elements	Type of Structure ^a					
	1.	2.	3.	4.	5.	6.
1. Abut. Bridge Seats	7	6	6	6	7	-
2. Abut. Wings	7	7	-	6	7	8
3. Abut. Backwall	6	7	6	6	7	-
4. Abut. Footing	-	-	6	-	-	-
5. Abut. Piles	-	-	-	-	-	-
6. Abut. Erosion	6	6	6	7	-	7
7. Abut. Settle.	7	7	6	-	-	-
8. Piers Caps	7	7	6	7	7	7
9. Piers Column	7	7	6	7	7	7
10. Piers Footing	-	-	6	-	-	-
11. Piers Piles	-	-	-	-	-	-
12. Piers Scour	7	7	6	7	-	-
13. Piers Settle.	7	7	7	-	-	-
14. Pile Bents	-	-	-	-	-	-
15. Cracks\Spalls	7	7	6	6	-	7
16. Steel Corrosion	-	-	-	-	-	-
17. Timber Decay	-	-	-	-	-	-
18. Debris	7	7	6	6	7	-
19. Paint	-	-	-	-	-	-
20. Collision Damage	7	7	7	-	-	-
Rating By Inspectors	6	7	6	6	7	7
Rating Model	6	7	6	6	7	7

a

1. Continuous Reinforced Concrete Girder
2. Steel Beam with Reinforced Concrete Approach
3. Reinforced Concrete Girder
4. Continuous Steel Beam
5. Continuous Reinforced Concrete Girder
6. Reinforced Concrete Girder

7.3.3 Analysis of Bridge Repair Condition Rating

As previously mentioned, the proposed bridge condition inference model can be used to examine how the overall condition of a bridge component would change as a result of certain improvement activities. For example, suppose that the wearing surface of a bridge deck has a rating of 3, an appropriate question would be: What is the overall deck condition if the rating of the wearing surface goes to 9? Similarly, if the bearing devices on a bridge superstructure have an initial rating of 6, what would be the overall superstructure condition if the bearing devices are improved to a rating of 9? The answers to these questions can be useful when they are used in conjunction with a bridge management system. This capability can provide additional information to the bridge management system, especially when performing bridge maintenance planning. Of course, any experienced bridge inspector should be able to answer these questions. However, when there are many bridges to be analyzed with each having many combinations of improvement strategies, it is highly desirable to have a machine available to perform this task.

In order to demonstrate the use of the proposed inference model to determine the overall component rating as a result of certain improvements, a number of bridge records from the existing data base were randomly selected. For each selected bridge, a number of critical subcomponents with condition ratings less than 9 were set to 9 to reflect repair or replacement of the subcomponents, and the overall condition rating of the component as predicted by the model was examined. The analysis of the change can indicate the sensitivity of the overall component rating to changes in subcomponent ratings.

The result of the repair analysis performed on the selected bridges is presented in Tables 7.6 through 7.10. For example, from Table 7.6 it can be observed that the initial rating of the deck of a reinforced concrete girder bridge is 6. If only the wearing surface is repaired, the overall deck rating increases to a value of 7. However, if the wearing surface, joint leakage, and the expansion joints are all repaired then the rating increases to a value of 8.

An examination of the results in Tables 7.6 to 7.10 reveals that depending upon the importance of a particular subcomponent, the lower the initial rating of the subcomponent, the greater is the change in the overall component condition rating. Also, the rate of change of the overall component condition rating is a function of the number of subcomponents being examined.

7.4 Concluding Remarks

The major limitation of the techniques shown above is that it cannot be easily solved by hand since the proposed technique involves significant computational effort. However, with the advent of modern computing equipment, these computational algorithms can be easily implemented. A software package for the above algorithm has been developed for this purpose. Besides computing the overall ratings of the deck, superstructure and substructure, it allows the user to perform inventory retrieve, instantaneous information updating, statistical analysis of data bases and remaining life prediction.

Although the proposed fuzzy inference model is to assist a bridge inspector in bridge inspection, it can be used by the central office to randomly check the reliability of the condition data submitted by the district bridge inspectors.

Table 7.6 Sensitivity Analysis of a Reinforced Concrete ^a Deck

DECK Elements	Initial State	Improvement Trials		
		1	2	3
1. Wearing Surface	3	9 <-	9 <-	9 <-
2. Deck-Structure	-	-	-	-
3. Curbs	7	7	7	7
4. Median	-	-	-	-
5. Sidewalks	7	7	7	7
6. Parapet	7	7	7	7
7. Railing	7	7	7	7
8. Paint	7	7	7	7
9. Drains	7	7	7	7
10. Lighting Standards	-	-	-	-
11. Utilities	-	-	-	-
12. Joint Leakage	6	6	9 <-	9 <-
13. Expansion Joints	6	6	6	9 <-
Rating Model	6	7	7	8

^a Continuous Reinforced Concrete Girder

<- Suggested Improvement

Table 7.7 Sensitivity Analysis of a Steel Bridge Deck ^a

DECK Elements	Initial State	Improvement Trials		
		1	2	3
1. Wearing Surface	4	9 <-	9 <-	9 <-
2. Deck Structure	5	5	5	5
3. Curbs	6	6	6	6
4. Median	-	-	-	-
5. Sidewalks	6	6	6	6
6. Parapet	-	-	-	-
7. Railing	6	6	6	6
8. Paint	7	7	7	7
9. Drains	6	6	6	6
10. Lighting Standards	-	-	-	-
11. Utilities	-	-	-	-
12. Joint Leakage	5	5	9 <-	9 <-
13. Expansion Joints	5	5	5	9 <-
Rating Model	5	6	6	7

^a Continuous Steel Beam

<- Suggested Improvement

Table 7.8 Sensitivity Analysis of a Reinforced Concrete Superstructure ^a

SUPERSTRUCTURE		Improvement Trials		
Elements	Initial State	1	2	3
1. Bearing Devices	6	9 <-	9 <-	9 <-
2. Stringers	-	-	-	-
3. Girder, Beams	7	7	9 <-	9 <-
4. Floor Beams	-	-	-	-
5. Trusses - General	-	-	-	-
6. Paint	6	6	6	6
7. Machinery	-	-	-	-
8. Rivets or Bolts	-	-	-	-
9. Welds - Cracks	-	-	-	-
10. Rust	6	6	6	6
11. Timber Decay	-	-	-	-
12. Concrete Cracking	7	7	7	7
13. Collision Damage	7	7	7	7
14. Deflection - Load	7	7	7	7
15. Alignment	6	6	6	9 <-
16. Vibrations	7	7	7	7
Rating Model	7	7	8	8

^a Continuous Reinforced Concrete Girder
 <- Suggested Improvement

Table 7.9 Sensitivity Analysis of a Steel Bridge Superstructure ^a

SUPERSTRUCTURE		Improvement Trials		
Elements	Initial State	1	2	3
1. Bearing Devices	7	9 <-	9 <-	9 <-
2. Stringers	-	-	-	-
3. Girder, Beams	7	7	9 <-	9 <-
4. Floor Beams	-	-	-	-
5. Trusses - General	-	-	-	-
6. Paint	7	7	7	7
7. Machinery	-	-	-	-
8. Rivets or Bolts	7	7	-	-
9. Welds - Cracks	-	-	-	-
10. Rust	7	7	7	7
11. Timber Decay	-	-	-	-
12. Concrete Cracking	-	-	-	7
13. Collision Damage	-	-	-	7
14. Deflection - Load	7	7	7	7
15. Alignment	7	7	7	9 <-
16. Vibrations	7	7	7	7
Rating Model	7	7	7	8

^a Continuous Steel Beam

<- Suggested Improvement

Table 7.10 Sensitivity Analysis of a Reinforced Concrete Bridge Substructure ^a

SUBSTRUCTURE		Improvement Trials		
Elements	Initial State	1	2	3
1. Abut. Bridge Seats	6	6	6	6
2. Abut. Wings	-	-	-	-
3. Abut. Backwall	6	9 <-	9 <-	9 <-
4. Abut. Footing	6	6	6	6
5. Abut. Piles	-	-	-	-
6. Abut. Erosion	6	6	6	6
7. Abut. Settle.	6	6	6	6
8. Piers Caps	6	6	6	9 <-
9. Piers Column	6	6	6	6
10. Piers Footing	6	6	9 <-	9 <-
11. Piers Piles	-	-	-	-
12. Piers Scour	6	6	6	6
13. Piers Settle.	7	7	7	7
14. Pile Bents	-	-	-	-
15. Cracks\Spalls	6	6	6	6
16. Steel Corrosion	-	-	-	-
17. Timber Decay	-	-	-	-
18. Debris	6	6	6	6
19. Paint	-	-	-	-
20. Collision Damage	7	7	7	7
Rating Model	6	6	6	7

^a Continuous Reinforced Concrete Girder

<- Suggested Improvement

CHAPTER 8

8.0 SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND
FUTURE RESEARCH

8.1 Summary

This report contains the findings of a bridge inspection research study that was undertaken to evaluate the bridge condition assessment procedures in Indiana and to develop a systematic condition evaluation procedure for the state of Indiana. The emphasis in the present study was on the development of a procedure that will promote consistency and enhance standardization of the bridge condition assessment process.

Bridge condition rating is a key parameter in determining the improvement strategies for the state-wide network of bridges. This, together with other inspection data, constitutes the basic input information in a bridge management system. It is desirable that the bridge condition data be collected in a consistent and systematic manner. In reality, such consistency is difficult to obtain because bridge inspection is by nature a subjective process which does not lend itself to precise assessments. The inspection data suffers from imprecision due to vagueness in information that prevails in the inspection environment.

In an effort to minimize the effects of such imprecision, a bridge structure is decomposed into simpler components and subcomponents. Specifically, the bridge is divided into three major components: deck, superstructure and substructure. Each component is further decomposed into simpler elements. Such bridge decomposition in the present work is accomplished by adopting the items listed under each component in the standard field inspec-

tion form. The main advantage of this approach is that it permits the use of all existing inspection data bases.

From interviews with the district bridge inspectors, it was found that the subjective judgment needed in determining the overall component condition rating is related to the assessment of the importance of the various subcomponents. Moreover, the importance factor of a subcomponent depends upon the physical condition of the subcomponent under investigation. The importance factors of the various subcomponents were elicited through questionnaires. Since there are presently no established guidelines available for the bridge inspectors to use when determining these importance factors, each bridge inspector will invariably perceive the importance of each subcomponent with some degree of uncertainty.

The theory of fuzzy sets is particularly suitable to handle this type of uncertainty. Consistent with fuzzy set principles, the importance factors are expressed in terms of membership functions rather than precise numerical estimates. To combine the rating of various subcomponents and their associated importance factors, a cumulative rating function is employed. The parameters in this function are fuzzy sets.

8.2 Conclusions

One of the findings of the present study is that current bridge inspection practices suffer from shortcomings due to the following inherent characteristics:

1. In general, bridge condition is evaluated based primarily on visual inspection
2. Personal judgment, bias and subjectiveness of bridge inspectors are not systematically accounted for in the present inspection process.

3. The current bridge inspection form should be improved. An inspection form should be developed for each bridge type, with detailed inspection elements included that are appropriate for the type of bridge structure.
4. No guidelines are available to define the relationship between the severity and the importance of deterioration in a bridge element.

In spite of these shortcomings, the present inspection practice serves its intended purpose of preventing tragic bridge failures and planning short term bridge repairs at the project level. However, modifications to the existing setup are necessary for the purpose of determining improvement strategies for a network of bridges or to satisfy the demands of a comprehensive bridge management system.

It is concluded that major inconsistencies are likely to occur in the overall bridge component rating. Subjective judgment and intuition are used to combine various subcomponent ratings to obtain the overall bridge component rating. To minimize the effect of such inconsistencies, a bridge inspection system was developed. This inspection system would establish the importance of various types of deterioration and account for the subjective judgment and personal bias that are part of bridge inspection.

The results obtained from the proposed inspection system were in good agreement with the actual results from experienced bridge inspectors. Based upon the results obtained in the present study, it is believed that the following uses for the proposed inspection system are possible:

- i] Although the proposed inspection system is designed to filter out inconsistencies in condition ratings from existing data bases, it can also be used to assist bridge inspectors in determining the rating of various bridge components during bridge inspection.
- ii] The program can be used at the central office to spot check the condition rating data supplied by the various district offices for any deviation from the norm.

- iii] During bridge improvement planning, the proposed system can be used to predict the bridge condition rating as a result of certain improvement activities.
- iv] In addition, this system can be incorporated as a tool for training new inspectors.
- v] Most importantly, this system will promote consistency in the bridge condition assessment among bridge inspectors and thus will permit bridge improvement strategies to be determined on a common ground.

Finally, it is concluded that the evaluation of the load carrying capacity of existing bridges should be based on the actual condition of the structure. Complete information on all relevant aspects of the design of a bridge, on any deterioration, settlement, imperfection and on the properties of materials should be incorporated into the assessment of bridge load carrying capacity.

8.3 Recommendations

The proposed bridge inspection system is designed to be used on a micro-computer. It is best implemented on a microcomputer that uses an advanced microprocessor and has a math co-processor. It is also desirable to have a hard disk installed in the computer. Since this system is also designed to be used at the inspection site, a hand-held or lap top computer with the above recommended requirements would be desirable. This technology is already available and it only needs to be adapted for bridge inspection.

This inspection system will assist a bridge inspector in collecting, updating and storing bridge rating data in the field rapidly. Other minor features of this bridge inspection system include the retrieval of previous inspection data, prediction of remaining life and suggestion of improvement needs. In Appendix D is given a program manual that discusses some of these features.

8.4 Future Research

A number of technological improvements will enhance the practice of bridge inspection. The first needed improvement is a method to obtain more realistic measures of bridge condition. Automated survey and condition rating techniques would improve the quality of the measurements of bridge condition and structural capacity. Simpler methods and equipment that enhance visual inspection of bridge deterioration would be extremely useful.

Techniques using laser technology are presently being employed in the measurement of pavement distresses. This technique can be adapted for inspecting bridge decks. Other automated techniques such as monitoring steel corrosion and measuring chloride content of decks would be beneficial. Methods of enhancing visual detection of fatigue cracks in steel bridge members should be explored. This is particularly important in steel bridges with single-load path members where an unrestricted and unimpaired crack could lead to catastrophic brittle fracture. Finally, methods should be developed to assess the degree of substructure distress from undercutting and scour. Flowing water that results in scour or bed lowering can be source of a potential danger for the load bearing capacity of a foundation. Changing ground water levels can have a significant influence on the stress pattern in the ground leading to unexpected and dangerous settlements.

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Appendix A

Fuzzy Importance Factors

A total of fifty-one sets of questionnaires were received from bridge inspectors, consultants and engineers in Indiana and the neighboring states. Five sets of questionnaires which did not conform to the instructions were excluded, leaving a total of forty six sets for this analysis.

Because of the large amount of data involved, computer programs were written to process and analyze the data. After all data were entered into the computer, a program was used to generate frequency plots for the various stages of deterioration of each subcomponent. From these frequency plots and using the point estimation method described in Chapter 5, membership functions of the various subcomponent importance factors for each of the five stages of deterioration were constructed. The membership functions of the various subcomponent importance factors are presented in this appendix from pages 185 through 233. Each fuzzy importance factor, y , has the following form:

$$y = [\mu_x | x]; \quad 0.0 \leq x \leq 1.0$$

where x is a positive real number denoting the structural importance of a subcomponent and μ_x is the degree of membership of x . The membership value is always a real number between zero and one, and it measures the extent to which an element is in a fuzzy set. The structural importance variable varies between zero and one, with numbers close to zero indicating weak (low) structural importance and close to one indicating a strong (high) importance.

The membership function of each importance factor can also be presented graphically. Graphical representation of the membership function of a fuzzy set enhances our ability to visualize the physical meaning and to understand the definition of the fuzzy set. For the purpose of illustration, the follow-

ing plots of membership function for stringers under different stages of deterioration demonstrate the change in structural importance.

Importance Coefficient of Stingers in Very Poor Condition

From this plot, it can be seen that the strongest support that stringers under very poor condition is 0.9, with no support that the importance is less than 0.3.

Importance Coefficient of Stingers in Poor Condition

Although the strongest support for stringers under poor condition is now 0.8, the membership function in this case is generally the same as in the

previous case.
Membership Value

Importance Coefficient of Stingers in Fair Condition

The point of strongest support for the importance coefficient of stringers under fair condition in this case is 0.7. As in the two previous cases, there is still not much change in the importance coefficient.

Membership Value

Importance Coefficient of Stingers in Good Condition

The point of strongest support of stringers under good condition is 0.6. The slight dip at the 0.5 point is called the point of concavity. This concavity phenomenon will be removed when the fuzzy importance factor is fitted by a π function described in Chapter 5.

Membership Value

Importance Coefficient of Stingers in Very Good Condition

From these plots, it can be concluded that the point of strongest support of the importance factor decreases as the condition of the stringers improves. However, it should be noted that such movement of the point of strongest support from one state of deterioration to another is quite small. The changes in the membership function from one state of deterioration to another can be best seen with the aid of three dimensional plots.

A three-dimensional plot of the membership functions for stringers is shown in Figure A1. The peak of each membership function in this figure denotes the point of maximum support. For the purpose of comparison, a similar plot for girders is shown in Figure A2. It can be concluded that the bridge girders are generally perceived to be slightly more important than stringers. It should be pointed out that the membership functions presented here have not been modified or refined to fit the S, Z or π functions.

A statistical evaluation of the data reveals that the mean value of an importance factor does not generally coincide with the point of maximum support. Figure A3 is a three dimensional plot showing how the average struc-

MEMBERSHIP FUNCTIONS FOR STRINGERS

Figure A1 Three Dimensional Plot of Membership Functions for Stringers

MEMBERSHIP FUNCTIONS FOR GIRDERS

Figure A2 Three Dimensional Plot of Membership Functions for Girders

AVERAGE IMPORTANCE VALUE FOR STRINGERS

Figure A3 Average Importance Values for Stringers

tural importance value varies with the various stages of deterioration. The mean value of the importance factor for stringers under very poor condition is approximately 0.81 while its point of maximum support is approximately 0.9. Similarly, the mean value of the importance factor for stringers under very good condition is approximately 0.44 whereas its point of maximum support is approximately 0.6. The $\pm$ one standard deviation values of the importance factor are also included in Figure A3. The standard deviation values are included to show the spread of the responses for each importance factor.

FUZZY IMPORTANCE FACTOR OF DECK ELEMENTS

DECK

TYPE: WEARING-SURFACE

CONDITION: VERY POOR RATING

[.0|.0 .4|.1 .6|.2 .6|.3 .7|.4 .8|.5 .9|.6 1.0|.7 .4|.8 .3|.9 .0|1.0]

DECK

TYPE: WEARING-SURFACE

CONDITION: POOR RATING

[.0|.0 .5|.1 .6|.2 .8|.3 .9|.4 1.0|.5 .8|.6 .4|.7 .4|.8 .3|.9 .0|1.0]

DECK

TYPE: WEARING-SURFACE

CONDITION: FAIR RATING

[.6|.0 .7|.1 .8|.2 1.0|.3 .9|.4 .8|.5 .4|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: WEARING-SURFACE

CONDITION: GOOD RATING

[.7|.0 .8|.1 1.0|.2 .9|.3 .3|.4 .1|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: WEARING-SURFACE

CONDITION: VERY GOOD RATING

[.9|.0 1.0|.1 .9|.2 .5|.3 .1|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DECK-CONDITION

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .3|.6 .5|.7 1.0|.8 .8|.9 .8|1.0]

DECK

TYPE: DECK-CONDITION

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .3|.5 .7|.6 .9|.7 1.0|.8 .8|.9 .3|1.0]

DECK

TYPE: DECK-CONDITION

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .3|.4 .4|.5 .8|.6 1.0|.7 .8|.8 .5|.9 .0|1.0]

DECK

TYPE: DECK-CONDITION

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .6|.4 .9|.5 1.0|.6 1.0|.7 .4|.8 .4|.9 .0|1.0]

DECK

TYPE: DECK-CONDITION

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .7|.4 1.0|.5 .9|.6 .7|.7 .6|.8 .0|.9 .0|1.0]

DECK
TYPE: CURBS

CONDITION: VERY POOR RATING

[.8|.0 1.0|.1 1.0|.2 .9|.3 .6|.4 .4|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK
TYPE: CURBS

CONDITION: POOR RATING

[.6|.0 .8|.1 1.0|.2 .6|.3 .3|.4 .1|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK
TYPE: CURBS

CONDITION: FAIR RATING

[.5|.0 1.0|.1 .5|.2 .3|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK
TYPE: CURBS

CONDITION: GOOD RATING

[1.0|.0 1.0|.1 .3|.2 .2|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK
TYPE: CURBS

CONDITION: VERY GOOD RATING

[1.0|.0 .8|.1 .4|.2 .0|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: MEDIAN

CONDITION: VERY POOR RATING

[.6|.0 1.0|.1 1.0|.2 .8|.3 .8|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: MEDIAN

CONDITION: POOR RATING

[.5|.0 1.0|.1 .8|.2 .8|.3 .3|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: MEDIAN

CONDITION: FAIR RATING

[.6|.0 1.0|.1 .6|.2 .3|.3 .0|.4 .1|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: MEDIAN

CONDITION: GOOD RATING

[1.0|.0 .9|.1 .4|.2 .2|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: MEDIAN

CONDITION: VERY GOOD RATING

[1.0|.0 .8|.1 .4|.2 .1|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: SIDEWALKS

CONDITION: VERY POOR RATING

[.0|.0 .3|.1 .8|.2 1.0|.3 .7|.4 .6|.5 .4|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: SIDEWALKS

CONDITION: POOR RATING

[.3|.0 .5|.1 1.0|.2 .7|.3 .6|.4 .5|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: SIDEWALKS

CONDITION: FAIR RATING

[.5|.0 1.0|.1 .8|.2 .4|.3 .6|.4 .3|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: SIDEWALKS

CONDITION: GOOD RATING

[1.0|.0 1.0|.1 .5|.2 .5|.3 .3|.4 .2|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: SIDEWALKS

CONDITION: VERY GOOD RATING

[.8|.0 1.0|.1 .3|.2 .3|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PARAPETS

CONDITION: VERY POOR RATING

[.5|.0 .5|.1 .7|.2 1.0|.3 .8|.4 .6|.5 .4|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PARAPETS

CONDITION: POOR RATING

[.4|.0 .5|.1 .7|.2 1.0|.3 .7|.4 .5|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PARAPETS

CONDITION: FAIR RATING

[.8|.0 .7|.1 .8|.2 1.0|.3 .7|.4 .3|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PARAPETS

CONDITION: GOOD RATING

[.8|.0 1.0|.1 .7|.2 .8|.3 .3|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PARAPETS

CONDITION: VERY GOOD RATING

[1.0|.0 .9|.1 .4|.2 .6|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

 DECK
 TYPE: RAILINGS CONDITION: VERY POOR RATING

[.0|.0 .2|.1 .5|.2 .8|.3 1.0|.4 .8|.5 .8|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

 DECK
 TYPE: RAILINGS CONDITION: POOR RATING

[0.0|.0 .4|.1 .7|.2 1.0|.3 .9|.4 .7|.5 .7|.6 .4|.7 .0|.8 .0|.9 .0|1.0]

 DECK
 TYPE: RAILINGS CONDITION: FAIR RATING

[0.3|.0 .6|.1 .8|.2 1.0|.3 .8|.4 .6|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

 DECK
 TYPE: RAILINGS CONDITION: GOOD RATING

[1.0|.0 .9|.1 .6|.2 .5|.3 .4|.4 .2|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

 DECK
 TYPE: RAILINGS CONDITION: VERY GOOD RATING

[1.0|.0 .8|.1 .7|.2 .5|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PAINT

CONDITION: VERY POOR RATING

[1.0|.0 .6|.1 .8|.2 .7|.3 .9|.4 .3|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PAINT

CONDITION: POOR RATING

[1.0|.0 .8|.1 .9|.2 .7|.3 .8|.4 .7|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PAINT

CONDITION: FAIR RATING

[1.0|.0 .9|.1 .9|.2 .9|.3 .5|.4 .3|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PAINT

CONDITION: GOOD RATING

[1.0|.0 .9|.1 .6|.2 .3|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: PAINT

CONDITION: VERY GOOD RATING

[1.0|.0 .8|.1 .4|.2 .3|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DRAINS

CONDITION: VERY POOR RATING

[.0|.0 .2|.1 .6|.2 .8|.3 1.0|.4 .7|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DRAINS

CONDITION: POOR RATING

[.0|.0 .2|.1 .8|.2 1.0|.3 .8|.4 .5|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DRAINS

CONDITION: FAIR RATING

[.0|.0 .6|.1 1.0|.2 .9|.3 .6|.4 .4|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DRAINS

CONDITION: GOOD RATING

[.7|.0 1.0|.1 1.0|.2 .9|.3 .7|.4 .3|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: DRAINS

CONDITION: VERY GOOD RATING

[.9|.0 1.0|.1 .8|.2 .4|.3 .3|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: LIGHTING

CONDITION: VERY POOR RATING

[1.0|.0 .9|.1 .8|.2 .7|.3 .5|.4 .2|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: LIGHTING

CONDITION: POOR RATING

[1.0|.0 .8|.1 .6|.2 .4|.3 .4|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: LIGHTING

CONDITION: FAIR RATING

[1.0|.0 .8|.1 .6|.2 .4|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: LIGHTING

CONDITION: GOOD RATING

[1.0|.0 .8|.1 .6|.2 .5|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: LIGHTING

CONDITION: VERY GOOD RATING

[1.0|.0 .9|.1 .8|.2 .5|.3 .1|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

```

-----
DECK
TYPE:    UTILITIES                      CONDITION: VERY POOR RATING
-----
[1.0|.0 .9|.1 .9|.2 .3|.3 .4|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]
*****

```

```

-----
DECK
TYPE:    UTILITIES                      CONDITION: POOR RATING
-----
[1.0|.0 .9|.1 .9|.2 .4|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]
*****

```

```

-----
DECK
TYPE:    UTILITIES                      CONDITION: FAIR RATING
-----
[1.0|.0 .9|.1 .9|.2 .3|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]
*****

```

```

-----
DECK
TYPE:    UTILITIES                      CONDITION: GOOD RATING
-----
[1.0|.0 .9|.1 .9|.2 .6|.3 .1|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]
*****

```

```

-----
DECK
TYPE:    UTILITIES                      CONDITION: VERY GOOD RATING
-----
[1.0|.0 .9|.1 .7|.2 .2|.3 .0|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]
*****

```

DECK

TYPE: JOINT-LEAKAGE

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .6|.4 .7|.5 .7|.6 1.0|.7 .6|.8 .6|.9 .3|1.0]

DECK

TYPE: JOINT-LEAKAGE

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .9|.4 .9|.5 1.0|.6 .8|.7 .7|.8 .3|.9 .0|1.0]

DECK

TYPE: JOINT-LEAKAGE

CONDITION: FAIR RATING

[.0|.0 .0|.1 .4|.2 .5|.3 .6|.4 1.0|.5 .5|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: JOINT-LEAKAGE

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .9|.3 1.0|.4 .8|.5 .4|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: JOINT-LEAKAGE

CONDITION: VERY GOOD RATING

[.8|.0 1.0|.1 .8|.2 .8|.3 .8|.4 .4|.5 .2|.6 .0|.7 .3|.8 .0|.9 .0|1.0]

DECK

TYPE: EXPANSION-JOINTS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .5|.4 .7|.5 .9|.6 .9|.7 1.0|.8 .5|.9 .4|1.0]

DECK

TYPE: EXPANSION-JOINTS

CONDITION: POOR RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .4|.4 .7|.5 .9|.6 1.0|.7 .6|.8 .4|.9 .2|1.0]

DECK

TYPE: EXPANSION-JOINTS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .5|.3 .8|.4 .9|.5 1.0|.6 .8|.7 .5|.8 .2|.9 .0|1.0]

DECK

TYPE: EXPANSION-JOINTS

CONDITION: GOOD RATING

[.0|.0 .4|.1 .6|.2 .8|.3 .9|.4 1.0|.5 .5|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

DECK

TYPE: EXPANSION-JOINTS

CONDITION: VERY GOOD RATING

[.8|.0 .8|.1 .9|.2 1.0|.3 .8|.4 .5|.5 .1|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

FUZZY IMPORTANCE FACTOR OF SUPERSTRUCTURE ELEMENTS

SUPERSTRUCTURE

TYPE: BEARING-DEVICES

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .4|.6 .6|.7 .8|.8 .9|.9 1.0|1.0]

SUPERSTRUCTURE

TYPE: BEARING-DEVICES

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .4|.5 1.0|.6 .8|.7 .8|.8 .8|.9 .4|1.0]

SUPERSTRUCTURE

TYPE: BEARING-DEVICES

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .7|.4 1.0|.5 .9|.6 .8|.7 .6|.8 .5|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: BEARING-DEVICES

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .6|.3 .8|.4 1.0|.5 .8|.6 .5|.7 .6|.8 .1|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: BEARING-DEVICES

CONDITION: VERY GOOD RATING

[.0|.0 .2|.1 .5|.2 .6|.3 .8|.4 1.0|.5 .8|.6 .5|.7 .4|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: STRINGERS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .1|.4 .2|.5 .3|.6 .6|.7 .8|.8 1.0|.9 .8|1.0]

SUPERSTRUCTURE

TYPE: STRINGERS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .6|.6 .8|.7 1.0|.8 .7|.9 .2|1.0]

SUPERSTRUCTURE

TYPE: STRINGERS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .5|.5 .5|.6 1.0|.7 .7|.8 .1|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: STRINGERS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .5|.3 .7|.4 .8|.5 1.0|.6 .7|.7 .2|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: STRINGERS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .5|.4 .9|.5 1.0|.6 .5|.7 .2|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: GIRDERS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .0|.6 .0|.7 .5|.8 .8|.9 1.0|1.0]

SUPERSTRUCTURE

TYPE: GIRDERS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .0|.6 .4|.7 .5|.8 1.0|.9 .5|1.0]

SUPERSTRUCTURE

TYPE: GIRDERS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .1|.5 .3|.6 .7|.7 1.0|.8 .8|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: GIRDERS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .6|.5 .8|.6 1.0|.7 .9|.8 .5|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: GIRDERS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .4|.4 .6|.5 1.0|.6 .7|.7 .5|.8 .4|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: FLOOR-BEAMS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .0|.6 .1|.7 .5|.8 .9|.9 1.0|1.0]

SUPERSTRUCTURE

TYPE: FLOOR-BEAMS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .3|.6 .4|.7 .8|.8 1.0|.9 .5|1.0]

SUPERSTRUCTURE

TYPE: FLOOR-BEAMS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .3|.6 .8|.7 1.0|.8 .5|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: FLOOR-BEAMS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .6|.5 1.0|.6 1.0|.7 .8|.8 .2|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: FLOOR-BEAMS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .7|.4 1.0|.5 1.0|.6 .9|.7 .5|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TRUSSES

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .3|.6 .6|.7 .7|.8 1.0|.9 .8|1.0]

SUPERSTRUCTURE

TYPE: TRUSSES

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .3|.5 .8|.6 .8|.7 1.0|.8 1.0|.9 .7|1.0]

SUPERSTRUCTURE

TYPE: TRUSSES

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .4|.5 .9|.6 1.0|.7 .9|.8 .7|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TRUSSES

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .8|.5 .9|.6 1.0|.7 .6|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TRUSSES

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .7|.4 1.0|.5 1.0|.6 .7|.7 .3|.8 .0|.9 .0|1.0]

 SUPERSTRUCTURE
 TYPE: PAINT

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .5|.3 .8|.4 .8|.5 .5|.6 1.0|.7 .3|.8 .0|.9 .0|1.0]

 SUPERSTRUCTURE
 TYPE: PAINT

CONDITION: POOR RATING

[.0|.0 .4|.1 .8|.2 .9|.3 1.0|.4 .8|.5 .8|.6 .5|.7 .1|.8 .0|.9 .0|1.0]

 SUPERSTRUCTURE
 TYPE: PAINT

CONDITION: FAIR RATING

[.0|.0 .4|.1 .7|.2 .9|.3 1.0|.4 .7|.5 .4|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

 SUPERSTRUCTURE
 TYPE: PAINT

CONDITION: GOOD RATING

[.0|.0 1.0|.1 .9|.2 .8|.3 .6|.4 .4|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

 SUPERSTRUCTURE
 TYPE: PAINT

CONDITION: VERY GOOD RATING

[1.0|.0 .7|.1 .5|.2 .5|.3 .3|.4 .1|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: MACHINERY

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .3|.5 .3|.6 .5|.7 .5|.8 1.0|.9 .9|1.0]

SUPERSTRUCTURE

TYPE: MACHINERY

CONDITION: POOR RATING

[.0|.0 .3|.1 .0|.2 .0|.3 .3|.4 .4|.5 .4|.6 .5|.7 1.0|.8 .9|.9 .4|1.0]

SUPERSTRUCTURE

TYPE: MACHINERY

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .6|.5 .8|.6 1.0|.7 .6|.8 .4|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: MACHINERY

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .7|.5 1.0|.6 .9|.7 .4|.8 .2|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: MACHINERY

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .2|.2 .6|.3 1.0|.4 .9|.5 .6|.6 .4|.7 .3|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: RIVETS-BOLTS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .3|.5 .4|.6 .6|.7 .8|.8 .9|.9 1.0|1.0]

SUPERSTRUCTURE

TYPE: RIVETS-BOLTS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .5|.6 .7|.7 1.0|.8 .7|.9 .4|1.0]

SUPERSTRUCTURE

TYPE: RIVETS-BOLTS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .4|.5 .6|.6 .8|.7 1.0|.8 .4|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: RIVETS-BOLTS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .6|.3 .8|.4 1.0|.5 .8|.6 .9|.7 .7|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: RIVETS-BOLTS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .4|.2 .5|.3 1.0|.4 1.0|.5 .8|.6 .4|.7 .1|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: WELDS-CRACKS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .0|.6 .1|.7 .4|.8 1.0|.9 .7|1.0]

SUPERSTRUCTURE

TYPE: WELDS-CRACKS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .2|.6 .4|.7 .7|.8 1.0|.9 .7|1.0]

SUPERSTRUCTURE

TYPE: WELDS-CRACKS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .9|.6 1.0|.7 .8|.8 .8|.9 .5|1.0]

SUPERSTRUCTURE

TYPE: WELDS-CRACKS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .3|.4 .5|.5 1.0|.6 .8|.7 .7|.8 .3|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: WELDS-CRACKS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .2|.2 .3|.3 .5|.4 .8|.5 1.0|.6 .9|.7 .8|.8 .4|.9 .0|1.0]

SUPERSTRUCTURE
TYPE: RUST

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .3|.5 .4|.6 .4|.7 .8|.8 1.0|.9 .6|1.0]

SUPERSTRUCTURE
TYPE: RUST

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .4|.4 .4|.5 .5|.6 .8|.7 1.0|.8 .7|.9 .4|1.0]

SUPERSTRUCTURE
TYPE: RUST

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .7|.4 1.0|.5 .8|.6 1.0|.7 .6|.8 .4|.9 .3|1.0]

SUPERSTRUCTURE
TYPE: RUST

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 1.0|.3 .7|.4 .6|.5 .8|.6 .4|.7 .2|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE
TYPE: RUST

CONDITION: VERY GOOD RATING

[.0|.0 1.0|.1 .7|.2 .6|.3 .5|.4 .5|.5 .4|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .3|.6 .5|.7 .7|.8 1.0|.9 .8|1.0]

SUPERSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .5|.6 .8|.7 1.0|.8 .7|.9 .5|1.0]

SUPERSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .8|.6 1.0|.7 .8|.8 .3|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .4|.4 .5|.5 1.0|.6 .8|.7 .4|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .2|.2 .5|.3 .8|.4 1.0|.5 .9|.6 .7|.7 .3|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .5|.6 .6|.7 .7|.8 .8|.9 1.0|1.0]

SUPERSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .6|.5 .8|.6 1.0|.7 1.0|.8 .5|.9 .2|1.0]

SUPERSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .5|.4 .6|.5 .7|.6 1.0|.7 .6|.8 .2|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .6|.3 .7|.4 .8|.5 1.0|.6 .8|.7 .3|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: VERY GOOD RATING

[.0|.0 .5|.1 .7|.2 .8|.3 .9|.4 .9|.5 1.0|.6 .7|.7 .4|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: COLLISION-DAMAGE

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .3|.5 .7|.6 1.0|.7 .8|.8 .5|.9 .3|1.0]

SUPERSTRUCTURE

TYPE: COLLISION-DAMAGE

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .7|.5 .9|.6 1.0|.7 .5|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: COLLISION-DAMAGE

CONDITION: FAIR RATING

[.0|.0 .0|.1 .3|.2 .4|.3 .6|.4 .8|.5 1.0|.6 1.0|.7 .3|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: COLLISION-DAMAGE

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .7|.3 1.0|.4 .9|.5 .8|.6 .7|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: COLLISION-DAMAGE

CONDITION: VERY GOOD RATING

[.6|.0 1.0|.1 .9|.2 .8|.3 .7|.4 .5|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: DEFLECTION

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .7|.5 .9|.6 1.0|.7 .9|.8 .7|.9 .5|1.0]

SUPERSTRUCTURE

TYPE: DEFLECTION

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .6|.4 1.0|.5 .9|.6 .9|.7 .9|.8 .7|.9 .7|1.0]

SUPERSTRUCTURE

TYPE: DEFLECTION

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .6|.3 1.0|.4 .9|.5 .9|.6 .8|.7 .5|.8 .2|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: DEFLECTION

CONDITION: GOOD RATING

[.0|.0 .2|.1 .7|.2 1.0|.3 .9|.4 .7|.5 .4|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: DEFLECTION

CONDITION: VERY GOOD RATING

[.4|.0 .5|.1 .7|.2 1.0|.3 .5|.4 .4|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: ALIGNMENT_MEMBER

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .7|.6 1.0|.7 .9|.8 .6|.9 .4|1.0]

SUPERSTRUCTURE

TYPE: ALIGNMENT_MEMBER

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .7|.4 .7|.5 1.0|.6 .9|.7 .8|.8 .5|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: ALIGNMENT_MEMBER

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .6|.3 .8|.4 .8|.5 1.0|.6 .7|.7 .4|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: ALIGNMENT_MEMBER

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .6|.6 .4|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: ALIGNMENT_MEMBER

CONDITION: VERY GOOD RATING

[.0|.0 .3|.1 .7|.2 1.0|.3 .9|.4 .8|.5 .5|.6 .4|.7 .2|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: VIBRATIONS_LOADS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .4|.4 .7|.5 .8|.6 1.0|.7 .7|.8 .5|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: VIBRATIONS_LOADS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .6|.4 .8|.5 1.0|.6 .8|.7 .6|.8 .4|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: VIBRATIONS_LOADS

CONDITION: FAIR RATING

[.0|.0 .2|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .8|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: VIBRATIONS_LOADS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .8|.3 1.0|.4 .9|.5 .5|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

SUPERSTRUCTURE

TYPE: VIBRATIONS_LOADS

CONDITION: VERY GOOD RATING

[.0|.0 .5|.1 .8|.2 1.0|.3 .7|.4 .5|.5 .4|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

FUZZY IMPORTANCE FACTOR OF SUBSTRUCTURE ELEMENTS

SUBSTRUCTURE

TYPE: BRIDGE-SEATS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .1|.4 .3|.5 .4|.6 .4|.7 .6|.8 1.0|.9 .5|1.0]

SUBSTRUCTURE

TYPE: BRIDGE-SEATS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .1|.3 .1|.4 .6|.5 .4|.6 .9|.7 1.0|.8 .4|.9 .3|1.0]

SUBSTRUCTURE

TYPE: BRIDGE-SEATS

CONDITION: FAIR RATING

[.0|.0 .2|.1 .2|.2 .3|.3 .5|.4 .9|.5 .5|.6 1.0|.7 .5|.8 .2|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BRIDGE-SEATS

CONDITION: GOOD RATING

[.0|.0 .3|.1 .4|.2 .6|.3 1.0|.4 1.0|.5 .9|.6 .7|.7 .2|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BRIDGE-SEATS

CONDITION: VERY GOOD RATING

[.0|.0 .4|.1 .6|.2 1.0|.3 .9|.4 .8|.5 .7|.6 .4|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: WINGS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .6|.4 1.0|.5 .8|.6 .6|.7 .4|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: WINGS

CONDITION: POOR RATING

[.0|.0 .0|.1 .2|.2 .5|.3 .7|.4 1.0|.5 .6|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: WINGS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .7|.2 1.0|.3 .8|.4 .7|.5 .4|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: WINGS

CONDITION: GOOD RATING

[.3|.0 .4|.1 .7|.2 1.0|.3 .7|.4 .5|.5 .4|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: WINGS

CONDITION: VERY GOOD RATING

[.3|.0 .8|.1 1.0|.2 .8|.3 .6|.4 .4|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BACKWALL

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .6|.5 .8|.6 .9|.7 1.0|.8 .5|.9 .2|1.0]

SUBSTRUCTURE

TYPE: BACKWALL

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .5|.4 .7|.5 .9|.6 1.0|.7 .6|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BACKWALL

CONDITION: FAIR RATING

[.0|.0 .0|.1 .3|.2 .5|.3 1.0|.4 .8|.5 .6|.6 .4|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BACKWALL

CONDITION: GOOD RATING

[.0|.0 .0|.1 .4|.2 .6|.3 .8|.4 1.0|.5 .7|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: BACKWALL

CONDITION: VERY GOOD RATING

[.0|.0 .2|.1 .5|.2 .7|.3 1.0|.4 .6|.5 .5|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: FOOTINGS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .6|.6 .8|.7 1.0|.8 .8|.9 .6|1.0]

SUBSTRUCTURE

TYPE: FOOTINGS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .6|.5 1.0|.6 1.0|.7 .8|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: FOOTINGS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .6|.4 1.0|.5 .8|.6 .6|.7 .4|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: FOOTINGS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .0|.2 .6|.3 .8|.4 1.0|.5 .6|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: FOOTINGS

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .8|.4 1.0|.5 .7|.6 .4|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PILES

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .7|.6 .8|.7 .9|.8 1.0|.9 .5|1.0]

SUBSTRUCTURE
TYPE: PILES

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .6|.5 .8|.6 .9|.7 1.0|.8 .6|.9 .2|1.0]

SUBSTRUCTURE
TYPE: PILES

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .5|.3 .7|.4 1.0|.5 .8|.6 .7|.7 .4|.8 .1|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PILES

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .6|.3 .8|.4 1.0|.5 .7|.6 .4|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PILES

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .5|.2 .7|.3 .9|.4 1.0|.5 .5|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: EROSION

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .5|.4 .7|.5 .8|.6 .9|.7 .9|.8 1.0|.9 .6|1.0]

SUBSTRUCTURE

TYPE: EROSION

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .6|.4 .8|.5 1.0|.6 .7|.7 .5|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: EROSION

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .6|.4 1.0|.5 .8|.6 .6|.7 .2|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: EROSION

CONDITION: GOOD RATING

[.4|.0 .6|.1 .8|.2 1.0|.3 .8|.4 .5|.5 .3|.6 .1|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: EROSION

CONDITION: VERY GOOD RATING

[.7|.0 .8|.1 .9|.2 1.0|.3 .7|.4 .6|.5 .6|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: SETTLEMENTS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .4|.5 .6|.6 .8|.7 .9|.8 1.0|.9 .8|1.0]

SUBSTRUCTURE

TYPE: SETTLEMENTS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .6|.5 1.0|.6 1.0|.7 .8|.8 .6|.9 .3|1.0]

SUBSTRUCTURE

TYPE: SETTLEMENTS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .7|.4 .8|.5 1.0|.6 .8|.7 .6|.8 .5|.9 .0|1.0]

SUBSTRUCTURE

TYPE: SETTLEMENTS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .4|.3 .5|.4 .8|.5 1.0|.6 .7|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: SETTLEMENTS

CONDITION: VERY GOOD RATING

[.0|.0 .2|.1 .5|.2 .6|.3 .7|.4 .8|.5 1.0|.6 .8|.7 .5|.8 .2|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-CAPS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .5|.6 .8|.7 1.0|.8 .8|.9 .5|1.0]

SUBSTRUCTURE

TYPE: PIERS-CAPS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .4|.5 .9|.6 1.0|.7 .5|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-CAPS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .6|.5 1.0|.6 .6|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-CAPS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .8|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-CAPS

CONDITION: VERY GOOD RATING

[.0|.0 .4|.1 .5|.2 .6|.3 .8|.4 1.0|.5 .5|.6 .4|.7 .2|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-COLUMN

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .4|.5 .5|.6 .6|.7 .7|.8 1.0|.9 .8|1.0]

SUBSTRUCTURE

TYPE: PIERS-COLUMN

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .1|.3 .3|.4 .5|.5 .7|.6 .9|.7 1.0|.8 .9|.9 .6|1.0]

SUBSTRUCTURE

TYPE: PIERS-COLUMN

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .4|.3 .6|.4 .8|.5 1.0|.6 .8|.7 .6|.8 .4|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-COLUMN

CONDITION: GOOD RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .6|.4 .8|.5 1.0|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-COLUMN

CONDITION: VERY GOOD RATING

[.0|.0 .3|.1 .6|.2 .9|.3 .9|.4 1.0|.5 .5|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-FOOTING

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .5|.5 .7|.6 .8|.7 .9|.8 1.0|.9 .8|1.0]

SUBSTRUCTURE

TYPE: PIERS-FOOTING

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .7|.5 1.0|.6 .9|.7 .7|.8 .5|.9 .3|1.0]

SUBSTRUCTURE

TYPE: PIERS-FOOTING

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .7|.4 .9|.5 1.0|.6 .8|.7 .7|.8 .4|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-FOOTING

CONDITION: GOOD RATING

[.0|.0 .2|.1 .5|.2 .7|.3 .9|.4 1.0|.5 .8|.6 .6|.7 .4|.8 .2|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-FOOTING

CONDITION: VERY GOOD RATING

[.0|.0 .3|.1 .5|.2 .7|.3 .9|.4 1.0|.5 .7|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-PILES

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .3|.5 .4|.6 .5|.7 .7|.8 1.0|.9 .7|1.0]

SUBSTRUCTURE

TYPE: PIERS-PILES

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .6|.5 1.0|.6 .8|.7 .5|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-PILES

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .5|.4 1.0|.5 .8|.6 .6|.7 .4|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-PILES

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .4|.3 .6|.4 1.0|.5 .6|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-PILES

CONDITION: VERY GOOD RATING

[.0|.0 .0|.1 .5|.2 .7|.3 .9|.4 1.0|.5 .6|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SCOUR

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .2|.5 .5|.6 .8|.7 1.0|.8 1.0|.9 .7|1.0]

SUBSTRUCTURE

TYPE: PIERS-SCOUR

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .5|.4 .7|.5 .9|.6 1.0|.7 .7|.8 .5|.9 .3|1.0]

SUBSTRUCTURE

TYPE: PIERS-SCOUR

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .6|.3 .8|.4 1.0|.5 .7|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SCOUR

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .8|.3 1.0|.4 .8|.5 .6|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SCOUR

CONDITION: VERY GOOD RATING

[.0|.0 .4|.1 .9|.2 1.0|.3 .9|.4 .7|.5 .2|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SETTLEMENT

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .3|.5 .5|.6 .7|.7 .9|.8 1.0|.9 .7|1.0]

SUBSTRUCTURE

TYPE: PIERS-SETTLEMENT

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .1|.4 .4|.5 .6|.6 .8|.7 1.0|.8 .5|.9 .3|1.0]

SUBSTRUCTURE

TYPE: PIERS-SETTLEMENT

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .5|.4 .7|.5 .8|.6 1.0|.7 .7|.8 .5|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SETTLEMENT

CONDITION: GOOD RATING

[.0|.0 .1|.1 .4|.2 .7|.3 .9|.4 .9|.5 1.0|.6 .7|.7 .4|.8 .1|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PIERS-SETTLEMENT

CONDITION: VERY GOOD RATING

[.0|.0 .1|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .8|.6 .6|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PILE-BENTS

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .3|.4 .5|.5 .7|.6 .8|.7 .9|.8 1.0|.9 .8|1.0]

SUBSTRUCTURE

TYPE: PILE-BENTS

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .6|.5 .8|.6 1.0|.7 .8|.8 .6|.9 .4|1.0]

SUBSTRUCTURE

TYPE: PILE-BENTS

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .5|.4 .7|.5 1.0|.6 .6|.7 .3|.8 .1|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PILE-BENTS

CONDITION: GOOD RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .7|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: PILE-BENTS

CONDITION: VERY GOOD RATING

[.0|.0 .1|.1 .4|.2 .7|.3 1.0|.4 .8|.5 .7|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .7|.5 1.0|.6 .8|.7 .8|.8 .8|.9 .5|1.0]

SUBSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: POOR RATING

[.0|.0 .0|.1 .2|.2 .3|.3 .6|.4 .9|.5 1.0|.6 .7|.7 .5|.8 .3|.9 .1|1.0]

SUBSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: FAIR RATING

[.0|.0 .0|.1 .2|.2 .5|.3 .7|.4 1.0|.5 .8|.6 .6|.7 .4|.8 .2|.9 .0|1.0]

SUBSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: GOOD RATING

[.1|.0 .3|.1 .5|.2 1.0|.3 .7|.4 .5|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: CONCRETE-CRACKIN

CONDITION: VERY GOOD RATING

[.7|.0 1.0|.1 .9|.2 .8|.3 .7|.4 .5|.5 .3|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: STEEL-CORROSION

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .5|.5 .8|.6 .9|.7 .9|.8 1.0|.9 .5|1.0]

SUBSTRUCTURE

TYPE: STEEL-CORROSION

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .3|.3 .6|.4 .8|.5 .9|.6 .9|.7 1.0|.8 .7|.9 .5|1.0]

SUBSTRUCTURE

TYPE: STEEL-CORROSION

CONDITION: FAIR RATING

[.0|.0 .0|.1 .3|.2 .6|.3 .9|.4 1.0|.5 .9|.6 .7|.7 .5|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: STEEL-CORROSION

CONDITION: GOOD RATING

[.2|.0 .5|.1 .8|.2 1.0|.3 .9|.4 .9|.5 .5|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: STEEL-CORROSION

CONDITION: VERY GOOD RATING

[.5|.0 .7|.1 .9|.2 1.0|.3 .7|.4 .5|.5 .3|.6 .2|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .0|.4 .0|.5 .1|.6 .3|.7 .6|.8 1.0|.9 .6|1.0]

SUBSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: POOR RATING

[.0|.0 .0|.1 .0|.2 .0|.3 .2|.4 .5|.5 .7|.6 1.0|.7 .9|.8 .4|.9 .1|1.0]

SUBSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: FAIR RATING

[.0|.0 .0|.1 .0|.2 .2|.3 .4|.4 .7|.5 1.0|.6 .8|.7 .6|.8 .3|.9 .0|1.0]

SUBSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: GOOD RATING

[.0|.0 .0|.1 .5|.2 .7|.3 .9|.4 1.0|.5 .9|.6 .7|.7 .4|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: TIMBER-DECAY

CONDITION: VERY GOOD RATING

[.6|.0 .8|.1 .9|.2 1.0|.3 .9|.4 .8|.5 .5|.6 .3|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: DEBRIS-SEATS

CONDITION: VERY POOR RATING

[.0|.0 .3|.1 .6|.2 .7|.3 .9|.4 1.0|.5 .7|.6 .5|.7 .3|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: DEBRIS-SEATS

CONDITION: POOR RATING

[.0|.0 .3|.1 .6|.2 .9|.3 1.0|.4 .7|.5 .4|.6 .1|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: DEBRIS-SEATS

CONDITION: FAIR RATING

[.1|.0 .6|.1 .8|.2 1.0|.3 .6|.4 .4|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: DEBRIS-SEATS

CONDITION: GOOD RATING

[.4|.0 .5|.1 1.0|.2 .5|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: DEBRIS-SEATS

CONDITION: VERY GOOD RATING

[.9|.0 1.0|.1 .9|.2 .4|.3 .1|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PAINT

CONDITION: VERY POOR RATING

[.1|.0 .3|.1 .6|.2 1.0|.3 .9|.4 .6|.5 .4|.6 .1|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PAINT

CONDITION: POOR RATING

[.0|.0 .3|.1 .5|.2 1.0|.3 .6|.4 .3|.5 .1|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PAINT

CONDITION: FAIR RATING

[.3|.0 .5|.1 .8|.2 1.0|.3 .6|.4 .3|.5 .1|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PAINT

CONDITION: GOOD RATING

[.7|.0 .8|.1 .9|.2 1.0|.3 .6|.4 .3|.5 .1|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE
TYPE: PAINT

CONDITION: VERY GOOD RATING

[1.0|.0 .8|.1 .6|.2 .4|.3 .2|.4 .0|.5 .0|.6 .0|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: COLLISION DAMAGE

CONDITION: VERY POOR RATING

[.0|.0 .0|.1 .2|.2 .4|.3 .6|.4 .8|.5 .8|.6 .9|.7 .9|.8 1.0|.9 .8|1.0]

SUBSTRUCTURE

TYPE: COLLISION DAMAGE

CONDITION: POOR RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .7|.4 .8|.5 .9|.6 1.0|.7 .8|.8 .6|.9 .4|1.0]

SUBSTRUCTURE

TYPE: COLLISION DAMAGE

CONDITION: FAIR RATING

[.0|.0 .0|.1 .3|.2 .5|.3 .7|.4 1.0|.5 .5|.6 .3|.7 .1|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: COLLISION DAMAGE

CONDITION: GOOD RATING

[.2|.0 .4|.1 .6|.2 .8|.3 1.0|.4 .7|.5 .4|.6 .1|.7 .0|.8 .0|.9 .0|1.0]

SUBSTRUCTURE

TYPE: COLLISION DAMAGE

CONDITION: VERY GOOD RATING

[.4|.0 .8|.1 .9|.2 1.0|.3 .7|.4 .5|.5 .4|.6 .1|.7 .0|.8 .0|.9 .0|1.0]

Appendix B

Sample Bridge Inspection Questionnaire Package

BRIDGE INSPECTION QUESTIONNAIRE PACKAGE

PURPOSE: The purpose of this survey is to study the relative structural importance of various bridge elements such as bearing devices, stringers, floor beams, etc. in a bridge rating process.

EXAMPLE: Suppose that a new superstructure is in excellent condition and a rating of 9, in the usual [0-9] scale, is assigned to all of the bridge elements. (See Table below). The question relevant to the survey is: "On a scale of [0.0 - 1.0], with 0.0 being insignificant and 1.0 being very significant, what is the importance of each element with respect to the overall structural safety?"

<u>Superstructure Element</u>	<u>Condition Rating</u>	<u>Structural Importance</u>
1. Bearing Devices	9	0.6
2. Stringers	9	0.3
3. Girders	9	0.7
4. Floor Beams	9	0.7
.		
.		
.		
Etc.		

The above example is for the purpose of illustration and the structural importance indicated may not necessarily be correct. In the above example, it was felt that the girders and floor beams are quite important structurally, and were given a 0.7 rating based on their importance. However, stringers were thought to be less important and were given a 0.3 rating.

In most cases, the condition ratings are less than 9. As the structure ages and the rating decreases, the structural importance may increase. In other words, when an element such as bearing device is in bad condition, i.e., rating of say 3, the element becomes more important because failure of bearing devices may lead to misalignment or even partial collapse of the structure. The figure below illustrates how the relative importance may vary for different conditions as discussed earlier.

To simplify the survey, the above graph is presented in a tabular format as shown below. Only 5 of the condition ratings are selected, instead of the usual [0-9] scale.

CONDITION RATING		STRUCTURAL IMPORTANCE										
		Insignificant					Significant					
#1	1	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
Bearing Devices	5	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
	7	0	.1	.2	.3	.4	(.5)	(.6)	(.7)	.8	.9	1.0
	9	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0

The bridge elements considered in present survey are the items in Sections 58 (Deck), 59 (Superstructure), and 60 (Substructure) in the Indiana bridge inspection form.

BRIDGE INSPECTION STUDY

Information released to us will be treated with the strictest confidentiality. The results of this survey in statistical or tabular format will be made available to interested parties, without disclosing the names of any firms or individual participants.

General Information

1. How many years of experience do you have in bridge inspection?

20

2. Please list (if any) all the states that you have ever done bridge inspection work.

PENNA., MARYLAND, WEST VIRGINIA & OHIO

3. Please list the types of bridges by highway classification that you have inspected (interstate, state, county, etc.):

Interstate, State, County, Borough & City

4. Would you like to have a copy of our report on this survey?

Yes [] No [☒]

If yes, please write your name and address below:

BRIDGE INSPECTION STUDY

ITEM No.: (58) DECK

	CONDITION	STRUCTURAL IMPORTANCE										
	RATING	Insignificant					Significant					
#1	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Wearing	5	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
Surface	7	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#2	1	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Deck- Structural Condition	5	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	7	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

#3	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Curbs	5	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#4	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
Median	5	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
	7	0	.1	.2	.3	(.4)	(.5)	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:*New Jersey Type*

BRIDGE INSPECTION STUDY

ITEM No: (58) DECK

	CONDITION	STRUCTURAL IMPORTANCE										
	RATING	Insignificant					Significant					
#5	1	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
Sidewalks	5	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	7	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

#6 Parapet	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
	5	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
	7	0	.1	.2	.3	(.4)	(.5)	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

New Jersey Type

#7 Railing	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
	5	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#8 Paint	1	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (58) DECK

CONDITION		STRUCTURAL IMPORTANCE										
RATING		Insignificant					Significant					
#9 Drains	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#10 Lighting Standard	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#11 Utilities	1	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#12 Joint Leakage	1	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (58) DECK

	CONDITION		STRUCTURAL IMPORTANCE									
	RATING		Insignificant					Significant				
#13	1	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Expansion	3	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
Joints or	5	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
Devices	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Possibly frozen, preventing structure movement.

#14	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#15	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#16	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (50) SUPERSTRUCTURE

	CONDITION		STRUCTURAL IMPORTANCE									
	RATING		Insignificant					Significant				
#1	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
Bearing	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Devices	7	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	9	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0

Notes:

#2	1	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	1.0
	3	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
Stringers	5	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
	7	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0

Notes:

#3	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	(1.0)
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	1.0
Girder, Beams or Arch Ring	5	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
	7	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
	9	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0

Notes:

Assuming 2-Girder, F.Bm. Construction

#4	1	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	1.0
	3	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
Floor Beams	5	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
	7	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (59) SUPERSTRUCTURE

	CONDITION	STRUCTURAL IMPORTANCE										
	RATING	Insignificant						Significant				
#5	1	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
Trusses-	3	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Portals	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Bracing	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes: *Assuming Portal; Sway Frame & Lateral Bracing.*

#6	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Paint	5	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#7	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
Machinery	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
(Movable-	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Spans)	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

#8	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Rivets or	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Bolts	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (59) SUPERSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE										
		Insignificant					Significant					
#9	1	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	1.0
	3	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
Welds-	5	0	.1	.2	.3	.4	(5)	(6)	.7	.8	.9	1.0
Cracks	7	0	.1	.2	.3	(4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes: Assume Fatigue Category E detail at girder flange or web.

#10	1	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
Rust	5	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	(0)	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#11	1	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Timber	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Decay	5	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	(0)	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#12	1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	(1.0)
	3	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	1.0
Concrete	5	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
Cracking	7	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	9	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0

Notes:

Assume stress cracks in concrete girder.

BRIDGE INSPECTION STUDY

ITEM No: (59) SUPERSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE										
		Insignificant					Significant					
#13	1	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	(1.0)
	3	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
Collision	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Damage	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#14	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Deflection	5	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
Under Load	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:*Steel stringer for example*

#15	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Alignment	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
of Members	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	(0)	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#16	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Vibrations	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Under Load	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:*High frequency in lateral bracing leading to fatigue cracking at connection to girder web.*

BRIDGE INSPECTION STUDY

ITEM No: (60) SUBSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE										
		Insignificant					Significant					
#1	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Abutments -	5	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
Bridge Seats	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#1	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Abutments -	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Wings	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Threatening embankment.

#1	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
Abutments -	3	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Backwall	5	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	7	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Supporting approach slab.

#1	1	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
Abutments -	5	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Footings	7	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (60) SUBSTRUCTURE

CONDITION RATING	STRUCTURAL IMPORTANCE											
	Insignificant						Significant					
1	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	
3	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	
5	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	
7	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	
9	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	

Notes:

#1	1	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	3	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
Abutments -	5	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
Erosion	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#1	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
Abutments -	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
Settlements	5	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Assuming continuous span structure!

#2	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
Piers or Bents -	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
Caps	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (60) SUBSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE									
		Insignificant					Significant				
#2	1	0	.1	.2	.3	.4	.5	.6	.7	(8)	(9) 1.0
	3	0	.1	.2	.3	.4	.5	.6	(7)	(8)	.9 1.0
Piers or Bents -	5	0	.1	.2	.3	.4	(5)	(6)	.7	.8	.9 1.0
Column	7	0	.1	.2	.3	(4)	.5	.6	.7	.8	.9 1.0
	9	0	.1	.2	(3)	.4	.5	.6	.7	.8	.9 1.0

Notes:

#2	1	0	.1	.2	.3	.4	.5	.6	(7)	(8)	.9 1.0
	3	0	.1	.2	.3	.4	.5	(6)	(7)	.8	.9 1.0
Piers or Bents -	5	0	.1	.2	.3	(4)	(5)	.6	.7	.8	.9 1.0
Footing	7	0	.1	.2	(3)	(4)	.5	.6	.7	.8	.9 1.0
	9	0	.1	(2)	(3)	.4	.5	.6	.7	.8	.9 1.0

Notes:

#2	1	0	.1	.2	.3	.4	.5	.6	(7)	(8)	.9 1.0
	3	0	.1	.2	.3	.4	.5	(6)	(7)	.8	.9 1.0
Piers or Bents -	5	0	.1	.2	.3	(4)	(5)	.6	.7	.8	.9 1.0
Piles	7	0	.1	.2	(3)	(4)	.5	.6	.7	.8	.9 1.0
	9	0	.1	(2)	(3)	.4	.5	.6	.7	.8	.9 1.0

Notes:

#2	1	0	.1	.2	.3	.4	.5	.6	(7)	.8	.9 1.0
	3	0	.1	.2	.3	.4	(5)	(6)	.7	.8	.9 1.0
Piers or Bents -	5	0	.1	.2	.3	(4)	(5)	.6	.7	.8	.9 1.0
Scour	7	0	.1	.2	(3)	(4)	.5	.6	.7	.8	.9 1.0
	9	0	.1	(2)	.3	.4	.5	.6	.7	.8	.9 1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No. (60) SUBSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE										
		Insignificant							Significant			
#2	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
	3	0	.1	.2	.3	.4	.5	(.6)	(.7)	.8	.9	1.0
Piers or Bents - Settlement	5	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#3	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	.9	1.0
	3	0	.1	.2	.3	.4	.5	.6	(.7)	.8	.9	1.0
Pile Bents	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
	7	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0

Notes:

#4	1	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
Concrete	3	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Cracking or	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Spalling	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

#5	1	0	.1	.2	.3	.4	.5	(.6)	.7	.8	.9	1.0
	3	0	.1	.2	.3	.4	(.5)	.6	.7	.8	.9	1.0
Steel	5	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
Corrosion	7	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

BRIDGE INSPECTION STUDY

ITEM No: (60) SUBSTRUCTURE

	CONDITION RATING	STRUCTURAL IMPORTANCE									
		Insignificant					Significant				
#6	1	0	.1	.2	.3	.4	.5	.6	.7	(.8)	1.0
	3	0	.1	.2	.3	.4	.5	.6	(.7)	.8	1.0
	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	1.0
	7	0	.1	.2	.3	(.4)	.5	.6	.7	.8	1.0
	9	0	.1	.2	(.3)	.4	.5	.6	.7	.8	1.0

Notes:

#7	1	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	3	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	5	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0
	9	(.0)	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Interfering with rocker movement.

#8	1	0	.1	.2	.3	(.4)	.5	.6	.7	.8	.9	1.0
	3	0	.1	.2	(.3)	.4	.5	.6	.7	.8	.9	1.0
	5	0	.1	(.2)	(.3)	.4	.5	.6	.7	.8	.9	1.0
	7	0	(.1)	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0
	9	0	(.1)	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Affected by location (climate dry or wet)

#9	1	0	.1	.2	.3	.4	.5	.6	.7	.8	(.9)	(1.0)
	3	0	.1	.2	.3	.4	.5	.6	(.7)	(.8)	.9	1.0
	5	0	.1	.2	.3	.4	(.5)	(.6)	.7	.8	.9	1.0
	7	0	.1	.2	(.3)	(.4)	.5	.6	.7	.8	.9	1.0
	9	0	.1	(.2)	.3	.4	.5	.6	.7	.8	.9	1.0

Notes:

Pier damage

Appendix C

Bridge Inspection Field Report and Structure Inventory & Appraisal Sheet

BRIDGE INSPECTION FIELD REPORT

Structure No. (8) 14-66-1242 District No. (2) 4 County No. (3) 66
 Route(5, 7) SR 14 Crossing(over)(under)(6) Dunker Ditch
 Location (9) 1.81 E US 421 Log Mile(11) 5.85
 Type-Main Spans(43) RCG & PCBB Type-Approach Spans (44) N/A
 No. Spans-Main(45) 1 No. Spans-Appr(46) N/A Span Lengths(48) 1 @ 40'
 No. Lanes(28)-On Str. 2 Under Str. N/A Skew(34) 45° RT Str.Length(49) 42'
 Total Horiz.Cl.(47) Ov. 30.6' Un. N/A Curb or Walk Width(50) Rt. 0.9' Lt. 0.9'
 Deck Width Curb to Curb(51) 30.6' Deck Width 0. to 0. Coping (52) 32.6'
 Min.Vertical Cl. over Deck(53) N/A Min.Vert.Cl.Under Str.(54) N/A
 Min.Horiz.Cl.Under Str.-Rt.(55) N/A Lt.(56) N/A Apprao.Rdwy.Width(32) 29'
 Traffic Safety Features(36) Br.Rail 1 Transition 0 Apprao.Rail 0 Terminal End 0
 City/Town Limit (4) N/A Inspector _____ Date 1-9-86

CONDITION

Under Remarks-show structural material and provide a narrative description of the condition of each and every item that is applicable to the bridge being inspected. Provide a photograph for every item which is rated 5 or below. (Use back of sheet for additional narrative and sketches showing location and extent of deficiencies.)

(58) DECKRating
(9-0)

REMARKS:

1. Wearing Surface	<u>6</u>	Additional Wearing Surface: - Type of Material <u>Asphalt</u>
2. Deck - Structural	<u>5</u>	
Condition		
3. Curbs	<u>6</u>	- Thickness of Material <u>2"</u> - Random Cracking - Salt Leaching thru Bays #1 & #5
4. Median	<u>-</u>	
5. Sidewalks	<u>-</u>	
6. Parapet	<u>6</u>	
7. Railing	<u>6</u>	
8. Paint	<u>-</u>	
9. Drains	<u>6</u>	
10. Lighting Standards	<u>-</u>	
11. Utilities	<u>-</u>	
12. Joint Leakage	<u>7</u>	longitudinal RCG/PCBB JT patched WITH NEW CONCRETE BY DISTRICT MAINT. 1984
13. Expansion Joints	<u>-</u>	
or Devices		

Inspectors Condition 6
 Rating

CHANNEL & CHANNEL
PROTECTIONRating
(9-0)REMARKS:

1. Channel Scour	6
2. Embankment Erosion	6
3. Drift	6
4. Vegetation	6
5. Channel Change	-
6. Fender System	-
7. Spur Dikes & Jetties	-
8. Rip Rap	-
9. Adequacy of Opening	6

Inspectors Condition Rating 6

(62) CULVERT & RETAINING WALLSRating
(9-0)REMARKS:

1. Barrell	
Concrete	
Steel	
Timber	
2. Headwall	
3. Cutoff Wall	
4. Adequacy	
5. Debris	

Inspectors Condition Rating N/A

(Rating given only for underfill structures)(63) ESTIMATED REMAINING LIFE

Inspectors appraisal of structural condition of structure 3 YRS.

(65) APPROACH ALIGNMENTRating
(9-0)REMARKS:

1. Alignment	6
2. Approach Slab	-
3. Relief Joints	-
4. Approach - Guardrail	-
- Pavement	6
- Embankment	6
- RANDOM MAP CRACKING

Inspectors Condition Rating 6

(66) RATED LOADINGRating
(9-0)

N/A

REMARKS:

1. Posted loading		Load Limit Posted _____ Tons at Bridge Site
2. Legibility		
3. Visibility		Load Limit Posted _____ Tons in Bridge Log Book

(59) SUPERSTRUCTURERating
(9-0)REMARKS:

1. Bearing Devices	7
2. Stringers	5
3. Girder, Beams, or Arch Ring	-
4. Floor Beams	-
5. Trusses - General	-
- Portals	-
- Bracing	-
6. Paint (Date	-
7. Machinery (Movable	-
Spans)	-
8. Rivets or Bolts	-
9. Welds - Cracks	-
10. Rust	-
11. Timber Decay	-
12. Concrete Cracking	5
13. Collision Damage	-
14. Deflection under load	6
15. Alignment of Members	6
16. Vibrations under load	7

#1 & #6 RCG's Bottom Spalled off. Rebar exposed
 (20 FT² x 2" 35 FT² x 2")

Inspectors Condition

6

Rating

(60) SUBSTRUCTURERating
(9-0)REMARKS:

1. Abutments - Bridge Seats	6
- Wings	6
- Backwall	6
- Footing	-
- Piles	-
- Erosion	6
- Settlement	6
2. Piers or Bents - Caps	-
(Stem) - Column	-
- Footing	-
- Piles	-
- Scour	-
- Settlement	-
3. Pile Bents	-
4. Concrete Cracking	6
or spalling	-
5. Steel Corrosion	-
6. Timber Decay, etc.	-
7. Debris on Seats	-
8. Paint	-
9. Collision Damage	-

- 1/2" CRACK W. below RCG #2
 1/4" CRACK E. below RCG #6

Inspectors Condition Rating

6

AISAL

Deficiencies:	Comments:	Rating (9-0)
(67) Structural Condition		6
(68) Deck Geometry		6
(69) Under Clearance (Vert. Horiz.)		-
(70) Safe Load Capacity		6
(71) Waterway Adequacy		6
(72) Approach Alignment		6

PROPOSED IMPROVEMENTS(73) Year Needed 1989(75) Type of Work ON HIP BRIDGE Replacement ProgramRemarks:

Numbers in brackets with item description referenced to item numbers in "Recording And Coding Guide For The Structure Inventory And Appraisal Of The Nation's Bridges Jan. 1979" of U.S. Department of Transportation/Federal Highway Administration.

STRUCTURE INVENTORY & APPRAISAL SHEET

Revised 12-78

IDENTIFICATION		CLASSIFICATION		By	Date
1 State <u>Indiana</u>		2 Fed Aid System <u>Local Rural Road</u>		Transfer of Data	
3 Hwy District <u>LaPorte</u>		4 Administrative <u>LaPorte County</u>		Maintenance Insp.	
5 County <u>LaPorte</u> 6 City/Town <u>N.A.</u>		7 Functional <u>Local</u>		Condition Analysis	
8 Inventory Route <u>110</u> On ☒ Under ☐				Appraisal	
9 Features Intersected <u>Trib. of Galena River</u>				Cost Estimate	
				General Review	
10 Facility Carried by Structure <u>C.R. 900N</u>		STRUCTURE DATA		11 Type Service <u>Highway/Waterway</u>	12
13 Structure No <u>630</u> 1 of <u>1</u>		14 Year Built <u>1980</u>		15 Structure Type <u>Main</u>	16 <u>P.C.Box Beam</u>
17 Location <u>0.5 Mi.E. of C.R. 425E</u>		18 Lanes on Str <u>2</u> under <u>0</u>		19 Approach <u>N.A.</u>	
19 Min. Vert Clearance, Inv. Rte. <u>N.A.</u>		20 ADT <u>100</u> 21 Year <u>1983</u>		22 No of Spans <u>Main</u>	
23 Milepoint <u>N.A.</u>		24 Design Load <u>HS-20</u>		25 Approach <u>N.A.</u>	
26 Road Section No <u>N.A.</u>		27 Appr Rdwy Width <u>20</u>		28 Total Horiz Clearance <u>23.0</u>	29 ft
30 Defense Bridge Description <u>N.A.</u>		31 B Median ☒ None ☐ Open ☐ Closed		32 Max Span Length <u>57</u>	33 ft
34 Defense Milepoint <u>N.A.</u>		35 Skew <u>13°</u>		36 Structure Length <u>61</u>	37 ft
38 Defense Section Length <u>N.A.</u>		39 Structure Flored ☐ Yes ☒ No		40 Sidewalk <u>N.A.</u>	41 ft, Lt <u>N.A.</u>
42 Latitude <u>N.A.</u>		43 Traffic Safety Feature <u>1111</u>		44 Br Roadway Width (curb to curb) <u>23.0</u>	45 ft
46 Longitude <u>N.A.</u>		47 Physical Vulnerability		48 Deck Width (out to out) <u>24.0</u>	49 ft
50 By pass, Detour Length <u>04</u>		51 Navigation Control ☐ Yes ☒ No		52 Vert Clearance over Deck <u>Unlimited</u>	53 ft
54 Toll Bridge ☐ On Toll Road ☐ On Free Road ☒		55 Vertical <u>N.A.</u>		56 Underclearance Vertical <u>N.A.</u>	57 ft
58 Custodian <u>LaPorte County</u>		59 Horizontal <u>N.A.</u>		60 Lateral Right <u>N.A.</u>	61 ft
62 Owner <u>LaPorte County</u>		63 Oper, Repaired, Closed <u>Open</u>		64 Left <u>N.A.</u>	65 ft
66 FAP No <u>N.A.</u>		67 Wearing Surface <u>Asphalt</u>			

CONDITION		Rating
Deck	Material <u>Asphalt over concrete</u>	9
Superstructure	<u>Prestressed box beams</u>	9
Substructure	<u>Concrete</u>	9
Channel & Channel Protection	<u>Concrete</u>	9
Culvert & Retaining Walls	<u>N.A.</u>	N
Estimated Remaining Life	<u>25 Yr.</u>	9
Operating Rating	<u>HS-28</u>	9
Condition Analysis		Fair
Approach Roadway Alignment		9
Inventory Rating		9

APPRAISAL		Rating
1 Structural Condition	<u>No deficiencies</u>	9
2 Deck Geometry		9
3 Underclearance Vertical & Lateral		N
4 Safe Load Capacity		9
5 Waterway Adequacy		9
6 Approach Roadway Alignment	<u>Sharp curve at east end of bridge</u>	8

PROPOSED IMPROVEMENTS		Rating
1 Year Needed <u>N.A.</u>	Completed <u>N.A.</u>	N.A.
2 Type of Service <u>N.A.</u>	Describe (Items)	N.A.
3 Type of Work <u>N.A.</u>		N.A.
4 Improvement Length <u>N.A.</u>	ft	N.A.
5 Design Loading <u>N.A.</u>		N.A.
6 Roadway Width <u>N.A.</u>	ft	N.A.
7 Number of Lanes <u>N.A.</u>	Prop Rdwy Improvement Year <u>N.A.</u>	N.A.
8 ADT <u>N.A.</u>	Year <u>N.A.</u>	N.A.

Cost of Improvements	\$	0	000	Remarks:
Prel. Engrg	\$	0	000	
Demolition	\$	0	000	
Substructure	\$	0	000	
Superstructure	\$	0	000	
Inspection Date	<u>2-8-83</u>			

Appendix E

Bridge Inspection System (BIS) User's Guide

BRIDGE INSPECTION SYSTEM

The Bridge Inspection System (BIS) was written in FORTRAN-77 and compiled using Microsoft Fortran Optimizing Compiler Version 4.0. It is designed to be implemented on an IBM PC or compatible microcomputer. It consists of approximately 60 pages of fortran code (see Appendix F). Figure D1 shows a simplified flow diagram of the BIS system.

There are seven basic modules in this program. Of these, the bridge condition module is perhaps the most important. It is also the focus of the present study. The database module controls the input and output file. Basically, it retrieves, updates and records new inspection information. It supplies the bridge condition module with previous inspection information, provided that such information is available in its database. It also stores new inspection information from the bridge condition module. The results of the bridge condition module goes to the remaining life module, the improvement recommendation module, the appraisal module, and the statistical analysis module. These modules can be easily expanded to include more features or perform more functions when necessary. The help module provides the bridge condition module with the FHWA definition of the various numerical rating variables. It can be further enhanced to include inspection guidelines for the various bridge elements.

The flowchart of the bridge condition module is shown in Figure D2. This module is in turn supported by many other modules. The data acquisition module provides the fuzzy information combination module with the various subcomponent condition ratings. Each numerical rating is then transformed into a fuzzy number by the internal fuzzy set representation module. The fuzzy importance coefficient module selects the fuzzy importance factor of

Figure D1. A Simplified Flowchart of the Bridge Inspection System

Figure D2. Flowchart of Bridge Component Condition Module

each subcomponent according to its condition rating. The fuzzy arithmetic operation module performs and controls the flow of the various fuzzy arithmetic computations.

The details of the information combination module is presented in Figure D3. The fuzzy data processing module processes the fuzzy rating and fuzzy importance coefficient information. The subroutine that performs the fuzzy data processing is called Compute in the BIS computer program. It supplies the lower and upper α -level sets information to the fuzzy condition inference module. The fuzzy condition inference module is contained in a subroutine called Alpcalc. The mapping of the fuzzy set defining the resultant condition to a fuzzy number is performed by a subroutine called Map in the program.

Figure D3. Flow chart of Bridge Information Combination Module

Appendix D

Implementation of Bridge Inspection System

GETTING STARTED

The BIS program is designed in such a way that the user does not need to know about the disk operating system (DOS) to use it. The DOS is a program that controls the general operation of a microcomputer. All DOS commands that are needed to run this system are described herein. It is assumed that the BIS user does not have any prior working knowledge or experience with a microcomputer.

A typical desktop computer system consists of three or more individual hardware components, including the computing unit, the keyboard, and the video monitor. The keyboard is used to enter information into the computer. The floppy disk drive is built into the computer to allow the storage and retrieval of information on removable floppy disks. A typical 5.25-inch floppy disk is capable of holding up to 180 pages of typewritten text. Even more storage is available on a hard disk drive. A 10 megabyte hard disk drive is capable of holding up to 5000 pages of typewritten text. The heart of the computer is the Central Processing Unit (CPU). The CPU processes information, performs arithmetic functions, and provides control for the rest of the system.

The BIS program can be implemented on both the desktop and portable laptop microcomputer. Although this program is designed to run on any microcomputer that uses DOS, it is best implemented on a desktop or laptop microcomputer that has an 80286 microprocessor, a math coprocessor and a hard disk for fast data access and information processing. A hard disk with at least a 10 megabyte storage capacity for every 3,000 bridges is highly desirable.

A floppy disk containing all the files necessary to run the BIS program is included with this report. Two sequences are described to load and run the BIS program.

Sequence One: To start the BIS program located in a Floppy Drive.

1. Put the BIS program disk in Drive A.
2. Type "A:BEGIN"

Sequence Two: To Load and Start the BIS program from the hard disk.

1. First, make a (sub)directory to hold the BIS program.

At C> Type " MKDIR BIS"

Next, copy all files from the floppy disk at A> prompt to the hard disk at C> prompt.

At C> Type " CD BIS "
At C> Type " COPY A:*. * "

This will copy all the files in the BIS diskette to the hard disk BIS (sub)directory. It should be noted that the above sequence is only one of the many ways of loading the BIS program into a hard disk.

2. At the (sub)directory containing the BIS program, Type "C:BEGIN "

It should be noted that the user does not have to use any commercial program such as DBASE, PARADOX, RBASE, KMAN, etc., or any language compiler or interpreter to run the BIS program. The program provided in the floppy disk has already been made executable.

INPUT GUIDE

This system contains user-friendly data input screens for easy data entry. The program prompts the user for all input data. The user does not have to memorize any commands such as to delete a certain entry, repeat, undo last entry, get help, enter remarks, etc., because all commands are described with simple keystrokes directly on the screen (henceforth referred to as menu). The following are some examples of the input menus. Since there are many menus in this program and all the menus are self-explanatory, only the most important menus are presented and described herein.

EXAMPLE MENUS

The BIS program interacts with the user through the use of menus. These menus allow the user to communicate with the computer. The extensive use of menus in this program permits the user to concentrate on the input questions without being distracted by input formats and commands.

OPENING MENU

MENU 1.0

B R I D G E I N S P E C T I O N
S Y S T E M

VERSION 1.0
JUNE 1988

For Further Information Contact:
Prof. Mark D. Bowman
Civil Engineering Department
Purdue University
West Lafayette, Indiana 47907
(317) 494-2220

Hit Return to Continue

The opening menu provides the user with a name and address to obtain further information or future updates. The version number is used to identify the extent of future modification on the BIS program. The version number will be changed according to the number of updates.

DATABASE MENU

MENU 1.0

MENU 2.0

I N P U T - O U T P U T
D A T A B A S E S

1. INPUT FILENAME = ?
2. OUTPUT FILENAME = ?
3. CHANGE FILENAME
4. CONTINUE

INPUT FILE = PREVIOUS INSPECTION FILE
OUTPUT FILE = NEW INSPECTION FILE

SELECT OPTION -->

This menu allows the user to specify the name of the input and output files. The input file is a database

containing previous inspection information such as condition ratings, general inventory information, remarks, etc. The output file is a file to hold the new inspection information.

MAIN MENU

```
SELECT OPTION -->1
```

In Menu 2.0, an input file usually contains many bridge records. Each bridge record is identified by a bridge number or structure number as in the field inspection form (see Appendix C).

When option 2 is selected, the BIS program will display the structure number and its corresponding location for every bridge in its database.

Selecting option 3 will prompt the BIS program to display the structure number of all bridges with poor deck, superstructure or substructure rating. This module can be further enhanced to include the listing of all bridges with a certain condition or a certain predicted remaining life, or to perform certain statistical analysis on the database such as the mean and standard deviation of the all condition ratings.

Option 4 allows the user to exit the BIS program. The brute force method of exiting this system at any time is by simply pressing the control (Ctrl) and Break Key on the keyboard simultaneously. However, exiting the system in this manner may result in the loss of the current inspection information.

The default option is option 1. Pressing the Enter or Return key on the keyboard is the same as selecting

option 1. The system will ask for the bridge number and then show the next menu.

GENERAL DATA MENU

MENU 3.0

MENU 4.0

**GENERAL DATA
MODULE**

1. ENTER INFORMATION FOR NEW BRIDGE
2. RETRIEVE INFORMATION FROM DATABASE
3. EXIT TO MAIN MENU

SELECT OPTION -->2

Option 1 should be used if the bridge to be inspected is a new bridge or if the database does not contain information of the bridge. It can also be used to create new database for existing bridges.

Selecting option 2 will prompt the system to display the general structure information of the bridge on the screen. The following is an example of such a screen.

```

===== MENU 5.0 =====
(1) STRUCTURE NO:= 1-65-139-2148      (2) DISTRICT NO:= 1
(3) COUNTY NO:= 86                   (4) ROUTE = 1-65
(5) CROSSING ROAD/RIVER = CORRAIL + PRAIRIE CR
(6) LOCATION = 0.55 MI N OF JCT 87   (7) LOG MILE = 141.40
(8) TYPE-MAIN SPANS = S3              (9) TYPE OF APPROACH SPANS = RC6
(10) NO.OF SPANS-MAIN = 1             (11) NO.OF SPANS- APPR =8
(12) SPAN LENGTHS = 78
(13) NO. LANES ON STR = 2
(14) SKEW = 38                        (15) NO. LANES UNDER STR = 2
(16) TOTAL HORIZ. CL. OVER = 35       (17) STR. LENGTH = 372
(18) CURB \ WALK WIDTH RT = 8.25     (19) TOTAL HORIZ. CL UNDER = 61
(20) CURB \ WALK WIDTH LT = 8        (21) DECK WIDTH CL-CL = 35
(22) DECK WIDTH S-S COPIING = 38     (23) MIN. VERT. CL. OVER DECK = -
(24) MIN. VERT. CL. UNDER STR. = 22'6" (25) MIN. HORIZ. CL. UN. STR. RT = 21'
(26) MIN. HORIZ. CL. UN. STR. LT = -  (27) APPROACH RDWY. WIDTH = 30
(28) SAFETY FEATURES BR. RAIL = 1     (29) TRANSITION = 1
(30) APPROACH RAIL = 1                (31) TERMINAL END = 1
(32) CITY/TOWN LIMIT = LEBANON       (33) INSPECTOR = M/A
(34) DATE = 1/1/86
=====
IS THE INFORMATION CORRECT ? (Y/N):
  
```

After examining the contents on this screen, the user has the option to change any item or continue with the next menu.

CONDITION MENU

MENU 5.0

MENU 6.0

CONDITION MODULE

1. DECK (58)
2. SUPERSTRUCTURE (59)
3. SUBSTRUCTURE (60)
4. CHANNEL PROTECTION (61)
5. CULVERT (62)
6. APPROACH ALIGNMENT (65)
7. POSTED LOADING (66)
8. EXIT TO APPRAISAL MODULE

SELECT OPTION -->1

This menu allows the user to begin inspection by selecting any one of the first seven options. Option 8 is reserved for the user to exit the condition module. Selecting any one of the first seven options will cause the system to generate an inspection screen for that option. An example of the deck inspection screen is shown in the next menu.

After answering all the inspection questions of the bridge component associated with the selected option, the above condition menu will reappear with the word "done" placed beside that option. This feature is particularly useful to users who do not begin with the first option or who do not have any fixed sequence of inspection.

If the user selects the same option twice, only the most current inspection information associated with that option is saved. This capability permits the user to redo a certain option as many times as necessary

INSPECTION MENU

MENU 6.0

MENU 7.0

* C O N D I T I O N *

* I N S P E C T I O N *

TYPE N = TO ENTER NOTES OR REMARKS
 U = TO UNDO LAST ENTRY
 - = FOR NOT APPLICABLE ENTRY
 H = FOR HELP
 0 - 9 = TO ENTER RATING
 (hit CTRL-BREAK to abort)
 (you may use capital or small letters)

T H E D E C K

ITEM (58)	PREVIOUS RATING	PRESENT RATING
1. WEAR SURFACE	[6]	=>6
2. DECK-STRUCTURAL CONDITION	[6]	=>5
3. CURBS	[-]	=>-
4. MEDIAN	[-]	=>-
5. SIDEWALKS	[5]	=>5
6. PARAPET	[6]	=>5
7. RAILING	[-]	=>-
8. PAINT	[-]	=>-
9. DRAINS	[6]	=>4
10. LIGHTING	[-]	=>-
11. UTILITIES	[-]	=>-
12. JOINT LEAKAGE	[4]	=>4
13. EXPANSION JOINTS OR DEVICES	[-]	=>-
PREVIOUS DECK RATING [6] COMPUTER RATING = [5]		
ENTER INSPECTOR'S CONDITION RATING ->		

This is an example of a deck inspection menu. The inspection menus for the deck, superstructure and substructure are some of the most important menus in this program. Based on the condition of the various subcomponents, the BIS program will compute the overall component condition rating. The component condition rating generated by the computer can be viewed as a consensus or major-

ity of opinion value. To promote uniformity and consistency in the rating of all bridges, it is recommended that the user accepts the computer generated ratings. However, the user is given the flexibility of overriding a computer generated rating and deciding on a different rating.

Another feature of the BIS program that can make the task of bridge inspection easier is its ability to retrieve previous inspection data from its database and present this information on the screen beside the inspection question. Since the condition of each subcomponent cannot improve by itself, the user can assume that the present condition of each subcomponent can either deteriorate or remain the same as the previous rating. Future expansion on this system may include a step by step tracing of the condition history of each subcomponent.

When all questions have been answered, Menu 6 will reappear. Selecting option 8 in Menu 6 will cause the next menu to appear.

APPRAISAL MENU

SELECT OPTION -->1

Selecting option 1 will prompt the system to compute the remaining life of the bridge. The prediction is based on the rating of the deck, superstructure, and substructure. If any one of the three component rating is not available, the system will return to the condition menu and prompt the user to begin inspecting that component.

Selecting option 2 will generate the deficiency appraisal menu similar to the inspection menu.

When option 3 is selected, the computer will generate a list of possible improvement needs. The user has the option of accepting or rejecting any of the proposed improvement needs.

Appendix F
Computer Program Listing

```

C
$INCLUDE: 'COVER.FOR'
C      COVER PAGE SUBPROGRAM
C
$INCLUDE: 'STATX.FOR'
C      STATISTIC SUBPROGRAM
C
$INCLUDE: 'DBN.FOR'
C      DATA BASE SUBPORGRAM
C
$INCLUDE: 'IDNO.FOR'
C      ID NUMBER SUBPROGRAM
C
$INCLUDE: 'WRT.FOR '
C      INPUT AND OUTPUT SUBPROGRAM
C
$INCLUDE: 'CALC.FOR'
C      FWA SUBPROGRAM

C
$INCLUDE: 'DEF.FOR'
C      DEFICIENCIES SUBPROGRAM
C
$INCLUDE: 'IMP.FOR'
C      IMPROVEMENT SUBPROGRAM
C
$INCLUDE: 'HLP.FOR'
C      HELP FILE
C
$INCLUDE: 'INSP.FOR'
C      INSPECTION SUBPROGRAM
$INCLUDE: 'GENDATA.FOR'
C      GENERAL DATA SUBPROGRAM
C
$INCLUDE: 'SAV.FOR'
C      SAVE INFO. SUBPROGRAM
C
C      THE BRIDGE INSPECTION SYSTEM
C      VERSION 2.0
C      PURDUE UNIVERSITY, WEST LAFAYETTE
C      JUNE 1988
C
10  WRITE(*,*) ' Please wait ..... '
    CALL MENU2
    GET MAIN MENU
20  WRITE(*, '(12X,A\))') ' DO YOU WISH TO QUIT ? <Y/N> '
    READ(*, '(A)')ANS1
    IF (ANS1 .EQ. 'Y' .OR. ANS1 .EQ. 'y') THEN
        CALL CLEAR
        CALL MENU1
        WRITE(*,*)
        STOP
    ELSE IF (ANS1 .EQ. 'N' .OR. ANS1 .EQ. 'n') THEN
        GO TO 10

```

```

        ELSE
        WRITE(*,*)'          SELECT Y=YES  '
        WRITE(*,*)'          N=NO    '
        GO TO 20
    ENDIF
STOP
END

C
    SUBROUTINE MENU2

C
    THIS IS THE MAIN MENU

    DIMENSION SIF(50,5,9)
    COMMON /WT/SIF

C
    OPEN DATA FILE CONTAINING IMPORTANCE FACTORS
C
    OPEN (UNIT=5,FILE='DATA.INP',STATUS='OLD')
    REWIND 5
    ISTORE=1

C
    READ PREVIOUS CONDITION RATING
C
    READ FUZZY STRUCTURAL IMPORTANCE VALUES
    DO 10 I=1,49
    DO 10 J=1,5
10    READ(5,*,END=15) (SIF(I,J,K), K=1,9)

15    CALL CLEAR
C
    CLEAR SCREEN
    CALL FILE
C
    INPUT AND OUTPUT FILENAME
30    CALL CLEAR
    WRITE(*,40)
    WRITE(*,50)
    READ(*,'(A)') ANS
    IF (ANS .EQ. '1' .OR. ANS .EQ. ' ') THEN
    CALL CLEAR
    CALL INITIAL

C
C
C
    INITIALIZE VARIABLES TO ZERO

    CALL INFO(IFLAG)
    IF (IFLAG.EQ.1) GO TO 30
35    IF (ISTORE.EQ. 0) THEN
36    WRITE(*,'(12X,A)') ' DO YOU WISH TO SAVE THIS DATA ? <Y/N> '
    READ(*,'(A)')ANS1
        IF (ANS1 .EQ. 'Y' .OR. ANS1 .EQ. 'y') THEN
        CALL STORE
        ISTORE=1
        ELSE IF (ANS1 .EQ. 'N' .OR. ANS1 .EQ. 'n') THEN
        ISTORE=1
        ELSE
        WRITE(*,*)'          SELECT Y=YES  '
        WRITE(*,*)'          N=NO    '
        GO TO 36
        ENDIF

```

```

ENDIF
CALL INSP
C
C BEGIN INSPECTION
C
CALL APRSL(JFLAG)
C
C BEGIN CONDITION APPRAISAL
C
IF (JFLAG.EQ.1) GO TO 35
C
C IFLAG CONTROLS DIRECTION OF INSPECTION
C
ISTORE=0
ELSE IF (ANS .EQ.'2') THEN
CALL CLEAR
CALL DBNL
C GET DATABASE
ELSE IF (ANS .EQ.'3') THEN
CALL CLEAR
CALL STAT
C GET STATISTICS
ELSE IF (ANS .EQ.'4') THEN
IF (ISTORE .EQ. 0) CALL STORE
ISTORE=1
C SAVE INFORMATION
ELSE IF (ANS .EQ.'5') THEN
IF (ISTORE .EQ. 0) THEN
37 WRITE(*, '(12X,A\)' ) ' DO YOU WISH TO SAVE THIS DATA ? <Y/N> '
READ(*, '(A\)' )ANS1
IF (ANS1 .EQ. 'Y' .OR. ANS1 .EQ. 'y') THEN
CALL STORE
ISTORE=1
GO TO 99
ELSE IF (ANS1 .EQ. 'N' .OR. ANS1 .EQ. 'n') THEN
GO TO 99
ELSE
WRITE(*,*) '          SELECT Y=YES   '
WRITE(*,*) '          N=NO    '
GO TO 37
ENDIF
ELSE
GO TO 99
ENDIF
ELSE
WRITE(*,60)
ENDIF
GO TO 30
40 FORMAT(15X, '*****',
&      /,15X, '*'   M A I N   M E N U   O P T I O N S   '*',
&      /,15X, '*'   -----                               '*',
&      /,15X, '*'                                     '*',
&      /,15X, '*'   1. BEGIN INSPECTION                               '*',
&      /,15X, '*'                                     '*',
&      /,15X, '*'   2. DISPLAY BRIDGE NUMBER AND LOCATION           '*',
&      /,15X, '*'                                     '*',
&      /,15X, '*'   3. STATISTICAL ANALYSIS                          '*'

```

```

&      /,15X,'*                               *',
&      /,15X,'*      4. SAVE INFORMATION        *',
&      /,15X,'*                               *',
&      /,15X,'*      5. QUIT                    *',
&      /,15X,'*                               *',
&      /,15X,'*      >> PRESS A NUMBER BETWEEN [1] AND [4] << *',
&      /,15X,'*****' )

```

```

50      FORMAT(/,12X,' SELECT OPTION --> '\)
60      FORMAT(/,12X,' INVALID OPTION - TRY AGAIN... ')
99      CLOSE(1)
        CLOSE(2)
        CLOSE(5)
        RETURN
        END

```

SUBROUTINE FILE

```

C
C      GET NAME OF INPUT AND OUTPUT FILES
C
C      CHARACTER INFILE*10, OUTFILE*10, ANSF1*5, ANSF2*5
C
        INFILE ='? '
        OUTFILE='? '
        INITIAL FILE VALUES
        CALL CLEAR
        WRITE(*,13) INFILE, OUTFILE
        WRITE(*,20)
        READ(*,'(A)')ANS
        IF (ANS .EQ. '1') THEN
7      WRITE(*,'(14X,A\)\')'ENTER NAME OF INPUT FILE --> '
        READ(*,'(A)') INFILE
        ANSF1='OLD'
        GO TO 5
        ELSE IF (ANS .EQ. '2') THEN
8      WRITE(*,'(14X,A\)\')'ENTER NAME OF OUTPUT FILE --> '
        READ(*,'(A)') OUTFILE
9      WRITE(*,'(14X,A\)\')'IS THIS A NEW OR OLD FILE ? < N=NEW/O=OLD > '
        READ(*,'(A)')ANSF
        IF (ANSF .EQ. 'n'.OR.ANSF.EQ. 'N')THEN
            ANSF2='NEW'
        ELSE IF (ANSF.EQ. 'o'.OR.ANSF.EQ. 'O')THEN
            ANSF2='OLD'
        ELSE
            WRITE(*,*)'      SELECT N=NEW  '
            WRITE(*,*)'      O=OLD    '
            GO TO 9
        ENDIF
        GO TO 5
        ELSE IF (ANS .EQ. '3') THEN
        WRITE(*,'(14X,A\)\')'CHANGE IN OR OUTPUT FILENAME ? <I=IN/O=OUT> '
        READ(*,'(A)')ANSF
        IF (ANSF .EQ. 'I'.OR.ANSF.EQ. 'i')THEN
            GOTO 7
        ELSE IF (ANSF.EQ. 'o'.OR.ANSF.EQ. 'O')THEN

```

```

        GOTO 8
    ENDIF
ELSE IF (ANS.EQ.'4') THEN
    IF (INFILE.EQ.'?' OR OUTFILE.EQ.'?') THEN
        CALL CLEAR
        WRITE(*,30)
        GO TO 6
    ENDIF
ELSE IF (ANS.EQ.'?') THEN
    CALL CLEAR
    WRITE(*,50)
    CALL WAIT
    GO TO 6
ELSE IF (ANS.EQ.' ') THEN
    IF (INFILE.EQ.'?' AND OUTFILE.EQ.'?') THEN
        INFILE='SAMPLE.INP'
        ANSF1='OLD'
        OUTFILE='SAMPLE.OUT'
        ANSF2='OLD'
    ENDIF
11 CALL CLEAR
    WRITE(*,15) INFILE, OUTFILE, ANSF1, ANSF2
    WRITE(*, '(//,14X,A\\)' ) ' IS THE INFORMATION CORRECT ? < Y/N > '
    READ(*, '(A)') ANS1
    IF (ANS1.EQ.'N' OR ANS1.EQ.'n') THEN
        GO TO 5
    ELSE IF (ANS1.EQ.'Y' OR ANS1.EQ.'y' OR ANS1.EQ.' ') THEN
        OPEN(UNIT=1, FILE=INFILE, STATUS='OLD')
C
C      INPUT FILE SHOULD BE AN OLD FILE
C
    REWIND(1)
    IF (ANSF2.EQ.'NEW') THEN
        OPEN(UNIT=2, FILE=OUTFILE, STATUS='UNKNOWN')
C
C      STATUS OF OUTPUT FILE MAYBE NEW OR OLD
C
    ELSE IF (ANSF2.EQ.'OLD') THEN
        OPEN(UNIT=2, FILE=OUTFILE, STATUS='OLD')
        RETURN
    ENDIF
    ELSE
        GO TO 11
    ENDIF
    ELSE
        WRITE(*,40)
        GO TO 6
    ENDIF
13 FORMAT(15X, '*****',
& /,15X, '          I N P U T - O U T P U T          ',
& /,15X, '          D A T A B A S E S          ',
& /,15X, '*****',
& /,15X, '          ',
& /,15X, '          1. INPUT FILENAME = ', A10, 2X, '          ',
& /,15X, '          ',
& /,15X, '          2. OUTPUT FILENAME = ', A10, 2X, '          ',
& /,15X, '          ')

```

```

&      /,15X,'*          3. CHANGE FILENAME                                *',
&      /,15X,'*                                                *',
&      /,15X,'*          4. CONTINUE                                    *',
&      /,15X,'*                                                *',
&      /,15X,'* *****'
&      /,15X,'* INPUT FILE = INPUT DATA BASE                        *',
&      /,15X,'* OUTPUT FILE = STORE NEW INSPECTION DATA            *',
&      /,15X,'* *****'
15  FORMAT(15X,'*****'
&      /,15X,'*          I N P U T - O U T P U T                        *',
&      /,15X,'*          D A T A B A S E S                                *',
&      /,15X,'* *****'
&      /,15X,'*          1. INPUT FILENAME      = ',A10,2X,' '          *',
&      /,15X,'*          2. OUTPUT FILENAME     = ',A10,2X,' '          *',
&      /,15X,'*          3. INPUT FILENAME      = ',A10,2X,' '          *',
&      /,15X,'*          4. OUTPUT FILENAME     = ',A10,2X,' '          *',
&      /,15X,'* *****'
&      /,15X,'*          INPUT FILE : {' ,A3,'} FILE',9X,' '          *',
&      /,15X,'*          OUTPUT FILE : {' ,A3,'} FILE',9X,' '          *',
&      /,15X,'* *****'

20  FORMAT(/,12X'  SELECT OPTION (<?=help> --> '\)
30  FORMAT(/,15X' +-----+
&      /,15X' | SELECT OPTION WITH ? FILENAME |',
&      /,15X' +-----+
40  FORMAT(/,12X'  INVALID OPTION ... RETRY '/')
50  FORMAT(/,15X' +-----+
&      /,15X' | Strike RETURN Key to Use Sample Databases |',
&      /,15X' | Hit 1 - To Specify Name of Input Database |',
&      /,15X' | Hit 2 - To Specify Output Filename |',
&      /,15X' | Hit 3 - Change Filenames |',
&      /,15X' | Hit 4 - Proceed |',
&      /,15X' +-----+

RETURN
END

SUBROUTINE INITIAL
C
C  INITIALIZE FUZZY VARIABLES
C
CHARACTER SVRATE(90)*2, REM(90)*30, BLANK*1, TICK(7)*6
CHARACTER SVC(10)*2
COMMON /SV/SVC
COMMON /SRT/SVRATE
COMMON /MSG/REM
COMMON TICK
DATA BLANK/' ' /
DO 5 I=1,10
SVC(I)='?'
DO 10 I=1,90
REM(I)=BLANK
C
C  SET REMARK OR MESSAGE VARIABLES TO BLANK
10  SVRATE(I)=BLANK
C
C  SET INITIAL SUBCOMPONENT RATINGS TO BLANK

```



```

20 DO 20 J=1,7
C   TICK(J)=BLANK
   INITIALIZE TICK (SEE INSP MODULE)
   RETURN
   END

```

```

10 SUBROUTINE WAIT
   WRITE(*,10)
   FORMAT(/,15X,'+-----+ ',
+        /,15X,'| Strike Return Key to Continue | ',
+        /,15X,'+-----+ \)')
   READ(*,'(A)') A
   WRITE(*,20)
20  FORMAT(25(/))
   RETURN
   END

```

```

C
C   THIS SUBPROGRAM IS CALLED COVER.FOR
C

```

```

C
C   SUBROUTINE MENU1
C
C   PRINT COVER PAGE. Version Number, Date and Contact Person
C
10  WRITE(*,10)
   FORMAT(15X,'*****',
&      /,15X,'*',
&      /,15X,'*   B R I D G E   I N S P E C T I O N   *',
&      /,15X,'*           S Y S T E M           *',
&      /,15X,'*                                   *',
&      /,15X,'*           VERSION 2.0           *',
&      /,15X,'*           JULY 1988             *',
&      /,15X,'*                                   *',
&      /,15X,'*   For Further Information Contact:   *',
&      /,15X,'*   Professor Mark D. Bowman             *',
&      /,15X,'*   Civil Engineering Department         *',
&      /,15X,'*   Purdue University                 *',
&      /,15X,'*   West Lafayette, Indiana 47907         *',
&      /,15X,'*   (317) 494-2220                       *',
&      /,15X,'*                                   *',
&      /,15X,'*****')
   RETURN
   END

```

```

C
C   THIS SUBPROGRAM IS CALLED INSP.FOR
C

```

```

C
C   SUBROUTINE INSP
C
C   BEGIN BRIDGE INSPECTION
C
   CHARACTER TICK(7)*6, IPRT(90)*2
   COMMON/PRT/IPRT
   COMMON TICK

```

C
C
C
20

TICK IS USED TO MARK ITEMS THAT HAVE BEEN COMPLETED

```

CALL CLEAR
WRITE(*,30)
WRITE(*,60) (TICK(I),I=1,7)
WRITE(*,40)
READ(*,'(A)')ANS
IF (ANS .EQ.'1') THEN
    CALL CLEAR
    TICK(1)='[DONE]'
    CALL INDATA('DECK',13)
ELSE IF (ANS .EQ.'2') THEN
    CALL CLEAR
    TICK(2)='[DONE]'
    CALL INDATA('SUPS',16)
ELSE IF (ANS .EQ.'3') THEN
    CALL CLEAR
    TICK(3)='[DONE]'
    CALL INDATA('SUBS',20)
ELSE IF (ANS .EQ.'4') THEN
    CALL CLEAR
    TICK(4)='[DONE]'
    CALL INDATA('CHNL',9)
ELSE IF (ANS .EQ.'5') THEN
    CALL CLEAR
    TICK(5)='[DONE]'
    CALL INDATA('CULV',7)
ELSE IF (ANS .EQ.'6') THEN
    CALL CLEAR
    TICK(6)='[DONE]'
    CALL INDATA('APPR',6)
ELSE IF (ANS .EQ.'7') THEN
    CALL CLEAR
    TICK(7)='[DONE]'
    CALL INDATA('LOAD',3)
ELSE IF (ANS .EQ.'8') THEN
    GO TO 99
ELSE
    WRITE(*,50)
ENDIF
WRITE(*,*) ' Hit Return To Continue ....'
READ(*,'(A)') A
GO TO 20

30  FORMAT(20X, 'OPTION MENU: '/
40  FORMAT(/,2X, ' SELECT OPTION ---> '\)
50  FORMAT(/,2X, ' INVALID OPTION - TRY AGAIN... ')

60  FORMAT(15X, '*****'
&    /,15X, '*' CONDITION MODULE
&    /,15X, '*' -----
&    /,15X, '*' 'A6,' 1. DECK (58)
&    /,15X, '*'
&    /,15X, '*' 'A6,' 2. SUPERSTRUCTURE (59)
&    /,15X, '*'
&    /,15X, '*' 'A6,' 3. SUBSTRUCTURE (60)
&    /,15X, '*'

```

```

&      /,15X,'* ',A6,'      4. CHANNEL PROTECTION (61)      *',
&      /,15X,'* '          *',
&      /,15X,'* ',A6,'      5. CULVERT (62)                  *',
&      /,15X,'* '          *',
&      /,15X,'* ',A6,'      6. APPROACH ALIGNMENT (65)       *',
&      /,15X,'* '          *',
&      /,15X,'* ',A6,'      7. POSTED LOADING (66)           *',
&      /,15X,'* '          *',
&      /,15X,'* '          8. EXIT TO APPRAISAL MODULE        *',
&      /,15X,'* '          *',
&      /,15X,'*****' )

```

```

99      RETURN
      END

```

```

      SUBROUTINE KEY
      WRITE(*,10)
10      FORMAT(15X,'+-----+','
&      /,15X,'|          ( Press Return To Continue )      '|',
&      /,15X,'+-----+' )
      RETURN
      END

```

```

C      SUBROUTINE INDATA(TYPE, NOEL)
C
C      ENTER INPUT DATA ROUTINE.
C      CONTROLS INPUT FORMAT - UNDO, HELP, MESSAGE
C
      CHARACTER TYPE*4, RATE(20)*2,MYRATE*2,ITEM*2
      COMMON /NRT/RATE

      DO 5 I=1,NOEL
5      RATE(I)='- '
      CALL INTRO(TYPE)
10      CALL ELTYPE(TYPE,1000)
      DO 40 I=1, NOEL
      IFMT=1000+I
20      CALL ELTYPE(TYPE,IFMT)
      READ(*,'(A2)') RATE(I)
      IF (RATE(I).EQ.'n '.OR.RATE(I).EQ.'N ') THEN
        CALL MESSAGE(TYPE,I)
        GO TO 20
      ELSE IF (RATE(I).EQ.'h '.OR.RATE(I).EQ.'H ')THEN
        CALL HELP(TYPE,I)
        GO TO 20
      ELSE IF (RATE(I).EQ.'u '.OR.RATE(I).EQ.'U ') THEN
        IF((IFMT-1).EQ.1000) GO TO 20
        CALL ELTYPE(TYPE,IFMT-1)
        READ(*,'(A2)')RATE(I-1)
        GO TO 20
      ELSE IF (RATE(I).EQ.'d '.OR.RATE(I).EQ.'D ') THEN
        WRITE(*,'(2X,A\)' ) ERASE ITEM NO: '
        READ(*,*) J
        CALL ELTYPE(TYPE,1000+J)
        READ(*,'(A2)')RATE(J)

```

```

      GO TO 20
ELSE IF (RATE(I).EQ.'r '.OR.RATE(I).EQ.'R ') THEN
      GO TO 6
ELSE IF (RATE(I).EQ.' '.OR.RATE(I).EQ.'- ') THEN
      GO TO 40
ELSE
      CALL ICHAR(RATE(I),J)
      IF (J.LT.0 .OR. J.GT. 9) THEN
          WRITE(*,99)
          GO TO 20
      ENDIF
ENDIF
40  CONTINUE

50  CALL REDRAW(TYPE)
C
C  SHOW INPUT INFORMATION - INPUT ACCURACY CHECKING
C
51  WRITE(*,'(1X,A\))' ARE THE RATINGS CORRECT ? <Y/N/?> '
      READ(*,'(A)') ANS
      IF (ANS.EQ.'N'.OR.ANS.EQ.'n') THEN
61  WRITE(*,'(1X,A\))' ENTER ITEM NO. '
          READ(*,'(A)') ITEM
          CALL JCHAR(ITEM,NOEL,I)
          IF (I.LT.0 .OR. I.GT.NOEL) THEN
              CALL REDRAW(TYPE)
              WRITE(*,100)
              GO TO 61
          ENDIF
          WRITE(*,'(1X,A\))' ENTER CORRECT VALUE or N=[REMARKS] '
          READ(*,'(A)') RATE(I)
          IF (RATE(I).EQ.'N'.OR.RATE(I).EQ.'n') THEN
              CALL MESSAGE(TYPE,I)
              CALL ELTYPE(TYPE,1000+I)
              READ(*,'(A)') RATE(I)
          ENDIF
          GO TO 50
      ELSE IF (ANS.EQ.'r '.OR.ANS.EQ.'R ') THEN
          GO TO 10
      ELSE IF (ANS.EQ.'y '.OR.ANS.EQ.'Y ') THEN
          IF (TYPE.NE.'LOAD') THEN
71  CALL REDRAW(TYPE)
              CALL FINAL(MYRATE)
          C
          C  ENTER THE OVERALL COMPONENT RATING
          C
              IF (MYRATE.EQ.'-') GO TO 81
              CALL ICHAR(MYRATE,J)
              IF (J.LT.0 .OR. J.GT. 9) THEN
                  WRITE(*,101)
                  CALL WAIT
                  GO TO 71
              ENDIF
81  CALL RML(TYPE,MYRATE)
          C
          C  SAVE INFORMATION FOR COMPUTING REMAINING LIFE
          C

```

```

      IF (TYPE.EQ.'DECK'.OR.TYPE.EQ.'SUPS'.OR.TYPE.EQ.'SUBS')
&      CALL SVCOND(TYPE,NOEL)

C      SAVE INFORMATION FOR IMPROVEMENT SUGGESTIONS
C
C      CALL SAVE2(TYPE,NOEL,MYRATE)
      ELSE
      CALL SAVE3(TYPE,NOEL)
      ENDIF
      ELSE
      WRITE(*,*)'      SELECT Y=YES  '
      WRITE(*,*)'      N=NO    '
      WRITE(*,*)'      R=REPEAT INSPECTION  '
      GO TO 51
      ENDIF

99      FORMAT(/,3X,'>> ENTER => N=[NOTES]  U=[UNDO]  H=[HELP]  -=[N/A]
& 0-9=[RATING] <<'/)
100     FORMAT(/,3X,'>> INVALID ITEM ... REPEAT << '/')
101     FORMAT(/,3X,'>> ENTER RATING BETWEEN 0 - 9 << '/')
      RETURN
      END

      SUBROUTINE ICHAR (RATING,IRATING)

C      CONVERT INPUT RATING TO INTEGER
C
      CHARACTER RATING*2,CHAR(10)*1
      DATA CHAR/'0','1','2','3','4','5','6','7','8','9'/
      IRATING=10
      DO 11 J=1,10
      IF (RATING .EQ. CHAR(J)) THEN
      IRATING=J-1
      RETURN
      ENDIF
11      CONTINUE
      RETURN
      END

      SUBROUTINE APRSL(JFLAG)

C      BEGIN BRIDGE APPRAISAL
C
      CHARACTER IPRT(90)*2,SVRATE(90)*2
      CHARACTER SVC(10)*2, VC(3)*2

C      COMMON/PRT/IPRT
      COMMON/SV/SVC
      COMMON/SRT/SVRATE
      JFLAG=0
      LIFE=0
      CALL CLEAR
      WRITE(*,30)
      WRITE(*,60)
      WRITE(*,40)
      READ(*,'(A)')ANS
      IF (ANS .EQ.'1') THEN

```

```

CALL CLEAR
IF(SVC(1).EQ.'?' .OR. SVC(2).EQ.'?' .OR. SVC(3).EQ.'?') THEN
  WRITE(*,65) SVC(1),SVC(2),SVC(3)
  JFLAG=1
C
C      JFLAG IS USED TO CHECK INFORMATION BEFORE
C      COMPUTING REMAINING LIFE

      CALL KEY
      READ(*,'(A)') A
      RETURN
ENDIF
DO 25 I=1,3
IF (SVC(I).EQ.'-') THEN
  VC(I)='0'
ELSE
  VC(I)=SVC(I)
ENDIF
25 CONTINUE
CALL ICHAR(VC(1),IDK)
CALL ICHAR(VC(2),ISP)
CALL ICHAR(VC(3),ISB)
CALL REMLIFE(IDK,ISP,ISB,LIFE)
C
C      COMPUTE REMAINING LIFE
C
      WRITE(*,70) (SVC(I),I=1,3),LIFE,IPRT(87)
      WRITE(*,75)
      READ (*,'(A)') SVRATE(87)
ELSE IF (ANS .EQ.'2') THEN
  CALL CLEAR
  CALL DFCY
C
C      GET DEFICIENCY ROUTINE
C
ELSE IF (ANS .EQ.'3') THEN
  CALL CLEAR
  CALL IMPROVE
C
C      GET IMPROVEMENT SUGGESTION MODULE
C
ELSE IF (ANS .EQ.'4') THEN
  JFLAG=1
  RETURN
ELSE IF (ANS .EQ.'5') THEN
  RETURN
ELSE
  WRITE(*,50)
  GO TO 21
ENDIF
GO TO 20
30 FORMAT(12X, 'OPTION MENU: '/
40 FORMAT(/,12X, ' SELECT OPTION ---> '\)
50 FORMAT(/,12X, ' INVALID OPTION - TRY AGAIN... ')
60 FORMAT(15X, '*****')
&      /,15X, '*' APPRAISAL MODULE '*'
&      /,15X, '*' ----- '*'

```

```

&      /,15X,'*
&      /,15X,'*      1. ESTIMATE REMAINING LIFE
&      /,15X,'*
&      /,15X,'*      2. DEFICIENCY APPRAISAL
&      /,15X,'*
&      /,15X,'*      3. PROPOSE IMPROVEMENTS
&      /,15X,'*
&      /,15X,'*      4. RETURN TO PREVIOUS MENU
&      /,15X,'*
&      /,15X,'*      5. EXIT TO MAIN MENU
&      /,15X,'*
&      /,15X,'*****'

```

```

65  FORMAT(15X,'*****'
&      /,15X,'*      S U G G E S T E D
&      /,15X,'*      R E M A I N I N G   L I F E
&      /,15X,'*****'
&      /,15X,'*      E S T I M A T E D       C O N D I T I O N
&      /,15X,'*
&      /,15X,'*      1. DECK                      = ',A2,5X'
&      /,15X,'*      2. SUPERSTRUCTURE           = ',A2,5X'
&      /,15X,'*      3. SUBSTRUCTURE              = ',A2,5X'
&      /,15X,'*
&      /,15X,'*      -----
&      /,15X,'*      YOU MUST FIRST ENTER THE CONDITION OF
&      /,15X,'*      OF THE ELEMENT(S) WITH ? RATING
&      /,15X,'*      -----
&      /,15X,'*
&      /,15X,'*****'

```

```

70  FORMAT(15X,'*****'
&      /,15X,'*      S U G G E S T E D
&      /,15X,'*      R E M A I N I N G   L I F E
&      /,15X,'*****'
&      /,15X,'*      E S T I M A T E D       C O N D I T I O N
&      /,15X,'*
&      /,15X,'*      1. DECK                      = ',A2,5X'
&      /,15X,'*      2. SUPERSTRUCTURE           = ',A2,5X'
&      /,15X,'*      3. SUBSTRUCTURE              = ',A2,5X'
&      /,15X,'*
&      /,15X,'*      -----
&      /,15X,'*      SUGGESTED REMAINING LIFE    = ',I2,5X'
&      /,15X,'*
&      /,15X,'*****'
&      /,15X,'*
&      /,15X,'*      PREVIOUS REMAINING LIFE      = ',A2,5X'
&      /,15X,'*
&      /,15X,'*****'
75  FORMAT(15X,'ENTER THE ESTIMATED BRIDGE REMAINING LIFE -> ',\))

```

THE BRIDGE INSPECTOR IS REQUIRED TO ENTER THE BRIDGE
REMAINING LIFE BASED ON THE SUGGESTED REMAINING LIFE.

```

99      RETURN
      END

C
C      THIS SUBPROGRAM IS CALLED GENDATA.FOR
C
C      SUBROUTINE INFO(IFLAG)
C
C      RETRIEVAL, UPDATA AND STORAGE OF GENERAL INFORMATION DATA
C      MODULE
C
      IFLAG=0
1      WRITE(*,5)
      WRITE(*,30)
      WRITE(*,10)
      READ(*,'(A)')ANS
      IF (ANS .EQ.'1') THEN
C          CALL NEW
C          ENTER NEW DATA
C          CALL SAVE1
C          SAVE INFORMATION
          RETURN
      ELSE IF (ANS .EQ.'2') THEN
C          CALL OLD
C          GET OLD DATA
C          CALL SAVE1
C          SAVE INFORMATION
          RETURN
      ELSE IF (ANS .EQ.'3') THEN
          IFLAG=1
C
C          RETURN TO MAIN MENU
C          DATA IS NOT SAVED
C
          RETURN
      ELSE
          WRITE(*,20)
      ENDIF
      GO TO 1
5      FORMAT(4(/),15X, 'OPTION MENU: '/
10     FORMAT(//,15X, ' SELECT OPTION ---> '\)
20     FORMAT(//,15X, ' INVALID OPTION - TRY AGAIN... ')
30     FORMAT( 15X, '*****',
&          /,15X, '*          G E N E R A L      D A T A          *',
&          /,15X, '*          M O D U L E          *',
&          /,15X, '*****',
&          /,15X, '*
&          /,15X, '*      1. ENTER INFORMATION FOR NEW BRIDGE      *',
&          /,15X, '*
&          /,15X, '*      2. RETRIEVE INFORMATION FROM DATABASE  *',
&          /,15X, '*
&          /,15X, '*      3. EXIT TO MAIN MENU                    *',
&          /,15X, '*
&          /,15X, '*****')
      RETURN

```


END

SUBROUTINE NEW

ENTER NEW INFORMATION

NO PREVIOUS DATABASE FOR THIS PARTICULAR BRIDGE

CHARACTER IPRT(90)*2

CHARACTER N(34)*20, BLANK*1

COMMON /BLK1/N

COMMON /PRT/IPRT

DATA BLANK/' '/

ENTRIES=34

DO 10 I=1,90

IPRT(I)='9'

SET SUBCOMPONENT RATINGS OF BRIDGE TO '9'

CALL CLEAR

CALL HEADER

DO 40 I=1, ENTRIES

LOOP FOR NUMBER OF ENTRY

CALL ENTRY(I)

READ(*,'(A)') N(I)

IF (N(I).EQ.'u' .OR. N(I) .EQ. 'U') THEN

UNDO LAST ENTRY

CALL ENTRY(I-1)

READ(*,'(A)') N(I-1)

GO TO 20

ELSE IF (N(I).EQ.'D'.OR. N(I).EQ.'d') THEN

DELETE A CERTAIN ITEM

WRITE(*,'(2X,A\))' ERASE ITEM NO: '

READ(*,*) J

CALL ENTRY(J)

READ(*,'(A)') N(J)

GO TO 20

ELSE IF (N(I).EQ.'r'.OR. N(I).EQ.'R') THEN

REPEAT FROM START

GO TO 15

ENDIF

CONTINUE

CALL DISPLAY

DISPLAY ALL ENTRIES

WRITE(*,'(1X,A\))' IS THE INFORMATION CORRECT ? <Y/N>'

READ(*,'(A)')ANS

IF (ANS .EQ.'N'.OR.ANS.EQ.'n')THEN

WRITE(*,'(1X,A\))' ENTER ITEM NO '

```

READ(*,*) I
WRITE(*, '(1X,A\\)') ' ENTER CORRECT VALUE '
READ(*, '(A)') N(I)
GO TO 50
ENDIF
RETURN
END

```

```

SUBROUTINE OLD

```

```

RETRIEVE PREVIOUS DATA BASE

```

```

CHARACTER N(34)*20, ISN*20
COMMON /BLK1/N
REWIND(1)
CALL CLEAR
WRITE(*,1000)
WRITE(*, '(10X,A\\)') ' ENTER BRIDGE NO: ->'
READ(*, '(A)') ISN
CALL CLEAR
IF (ISN.EQ.' ') GO TO 9
IF (ISN.EQ.'h'.OR.ISN.EQ.'H'.OR.ISN.EQ.'?') CALL ID(ISN)
WRITE(*, '(10X,A)') ' Begin Searching... '
WRITE(*, '(10X,A)') ' Please wait.... '
CALL SORT(ISN,IFLAG)
IF (IFLAG.EQ.1) THEN
WRITE(*,*) ' +-----+ '
WRITE(*,*) ' | STRUCTURE NUMBER NOT FOUND - RETRY | '
WRITE(*,*) ' +-----+ '
GO TO 10
ENDIF

```

```

IFLAG = 0 STRUCTURE NUMBER FOUND
IFLAG = 1 BRIDGE STRUCTURE NOT FOUND

```

```

CALL DISPLAY
WRITE(*, '(1X,A\\)') ' IS THE INFORMATION CORRECT ? <Y/N>'
READ(*, '(A1)')ANS
IF (ANS .EQ.'N'.OR.ANS.EQ.'n')THEN
WRITE(*, '(1X,A\\)') ' ENTER ITEM NO '
READ(*,*) I
WRITE(*, '(1X,A\\)') ' ENTER CORRECT VALUE '
READ(*, '(A20)') N(I)
GO TO 20
ENDIF

```

```

1000 FORMAT(15X, '*****',
& /,15X, ' SEARCHING FOR ',
& /,15X, ' BRIDGE ',
& /,15X, ' INFORMATION ',
& /,15X, '*****',
& /,15X, ' press "?" for a listing of bridge numbers ',
& /,15X, ' in the input database. ' //

```

```

RETURN
END

```

SUBROUTINE SAVE1

SAVE INFORMATION IN FILE

CHARACTER N(34)*20

COMMON/BLK1/N

WRITE(2,1) (N(I), I=1,34)

FORMAT(1X,A15,1X,A3,1X,A4,1X,A5,1X,A20,1X,A20,/,

& 1X,A8,1X,A6,1X,A6,1X,A4,1X,A4,1X,A20,1X,A5,1X,A5,1X,A5,/,

& 1X,A6,1X,A7,1X,A7,1X,A5,1X,A5,1X,A6,1X,A6,1X,A6,1X,A6,1X,A6/,

& 1X,A6,1X,A6,1X,A3,1X,A3,1X,A3,1X,A3,1X,A15,1X,A15,1X,A10)

RETURN

END

SUBROUTINE DISPLAY

SUBPROGRAM TO DISPLAY INPUT INFO. & CHECK FOR ACCURACY

CHARACTER N(34)*20

COMMON/BLK1/N

WRITE(*,99)

WRITE(*,*)

CALL BORDER

WRITE(*,1) (N(I), I=1,34)

FORMAT(2X,'(1) STRUCTURE NO:= ',A18,'(2) DISTRICT NO:= ',A5,

& /,2X,'(3) COUNTY NO:= ',A5,16X,'(4) ROUTE = ',A5,/,2X,

& '(5) CROSSING ROAD/RIVER = 'A20,

& /,2X,'(6) LOCATION = ',A20,1X,'(7) LOG MILE = ',A10,

& /,2X,'(8) TYPE OF MAIN SPANS = ',A6, 6X,'(9) TYPE OF APPR. SPANS

& = ',A8, /,1X,'(10) NO.OF SPANS-MAIN = ',A5, 8X,'(11) NO.OF SPANS-

& APPROACH = ',A8,/,1X,'(12) SPAN LENGTHS = ',A20,

& /,1X,'(13) NO. LANES ON STR = ',A10,3X,'(14) NO. LANES UNDER STR

& = ',A10,/,1X,'(15) SKEW = ',A5,20X,'(16) STR. LENGTH = ',A6,

& /,1X,'(17) TOTAL HOR. CL. OVER = ',A10, '(18) TOTAL HOR. CL. U

& NDER = ',A8, /,1X,'(19) CURB \ WALK WIDTH RT = ',A9, '(20)

& CURB \ WALK WIDTH LT = ',A5, /,1X,'(21) DECK WIDTH CURB-CURB = ',

& A8,1X,'(22) DECK WIDTH 0-0 COPING = ',A8,

& /,1X,'(23) MIN. VERT.CL.OV.DECK = ',A8,1X,'(24) MIN.VERT CL.UN.

& STR. = ',A7,/,1X,'(25) MIN.HOR.CL.UN.STR.RT = ',A9,'(26) MIN.HOR.C

& L.UN.STR.LT = ',A8,/,1X,'(27) APPROACH RDWY. WIDTH = ',A8,

& /,1X,'(28) SAFETY FEATURES BR.RAIL = ',A5,1X,

& '(29) TRANSITION = ',A5,/,1X,'(30) APPROACH RAIL = ',A13,3X,'(31)

& TERMINAL END = ',A5, /,1X,'(32) CITY LIMIT = ',A18,1X,'(33) INSP

& ECTOR = ',A20,/,1X,'(34) DATE = ',A10)

CALL BORDER

FORMAT(23X,30H BRIDGE INVENTORY INFORMATION

& /,23X,30H =====)

RETURN

END

SUBROUTINE SORT(ISN, IFLAG)

TEST GIVEN ISN WITH EXISTING DATABASE

CHARACTER REM(90)*30,IPRT(90)*2

CHARACTER ISN*20

```

CHARACTER N(34)*20
COMMON /BLK1/N
COMMON /PRT/IPRT
COMMON /MSG/REM

```

```

REWIND(1)
IFLAG=0

```

```

C      READ BRIDGE NUMBER

```

```

5      READ(1,6,END=999) (N(I),I=1,6)
6      FORMAT(1X,A15,1X,A3,1X,A4,1X,A5,1X,A20,1X,A20)

```

```

C      IF NO MORE DATA GO TO STATEMENT 999

```

```

      IF (N(1) .EQ. ISN) THEN

```

```

C      MATCH FOUND
C      READ THE REMAINING INFO.

```

```

      READ(1,10) (N(I), I=7,34)
10     &  FORMAT(1X,A8,1X,A6,1X,A6,1X,A4,1X,A4,1X,A20,1X,A5,1X,A5,1X,A5,
& 1X,A6,1X,A7,1X,A7,1X,A5,1X,A5,1X,A6,1X,A6,1X,A6,1X,A6,1X,A6/,
& 1X,A6,1X,A6,1X,A3,1X,A3,1X,A3,1X,A3,1X,A15,1X,A15,1X,A10)
      K=0
      DO 20 J=1,44
      READ(1,30) (IPRT(I+K), REM(I+K), I=1,2)
20     K=K+2
30     FORMAT(1X,2(2X,A2,2X,A30))
      RETURN
      ELSE

```

```

C      SKIP READING THE REST OF THE DATA

```

```

      READ(1,50)
50     FORMAT(46(/))

```

```

C      LOOP - GET ANOTHER RECORD
C

```

```

      GO TO 5
      ENDIF

```

```

999    IFLAG=1

```

```

C      END OF FILE REACHED
C      BRIDGE STRUCTURE NUMBER NOT FOUND

```

```

      RETURN
      END

```

```

SUBROUTINE HEADER

```

```

C
C      WRITE HEADER
C

```

```

      WRITE(*,10)
10     FORMAT(15X,'*****',)

```

```

&      /,15X,'*                B R I D G E                *,
&      /,15X,'*                I N V E N T O R Y          *,
&      /,15X,'*                I N F O R M A T I O N        *,
&      /,15X,'*****
&      /,15X,'      YOU MAY USE:
&      /,15X,'      small or CAPITAL LETTERS
&      /,15X,'      SYMBOLS SUCH AS 3 @ 120"
&      /,15X,'
&      /,15X,'      YOU WILL BE PROMPTED TO MAKE ANY
&      /,15X,'      CORRECTIONS AFTER ANSWERING ALL
&      /,15X,'      QUESTIONS.
&      /,15X,'
&      /,15X,'      TO ERASE: TYPE
&      /,15X,'      u or U [undo] last item
&      /,15X,'      d or D [delete] an item
&      /,15X,'      r or R [repeat] starting from beginning ',//)

```

```

RETURN
END

```

```

C
C      THIS SUBPROGRAM IS CALLED CALC.FOR
C

```

```

C      SUBROUTINE COMPUTE(NOEL,ILOC)
C

```

```

C      COMBINE THE VARIOUS SUBCOMPONENT RATINGS USING
C      THE INDIRECT METHOD. THE MEMBERSHIP DOMAIN IS
C      FIXED BY ALPHA CUTS. CALCULATION IS PERFORMED
C      ON THE VARIABLE DOMAIN
C

```

```

      DIMENSION IRATE(20),SIF(50,5,9), ALPVAL(20,9), FUZRATE(20,9)
      CHARACTER RATE(20)*2, CHAR(10)*1
      COMMON /NRT/RATE
      COMMON /WT/SIF
      DATA CHAR/'0','1','2','3','4','5','6','7','8','9'/

```

```

C      INITIALIZING.....
C

```

```

      DO 5 I=1,NOEL
      DO 5 J=1,9
      ALPVAL(I,J)=0.00
      FUZRATE(I,J)=0.01
5
C
C

```

```

      BEGIN ALPHA COMPUTATION
C

```

```

      DO 10 I=1,NOEL
      IF (RATE(I).EQ.'-'.OR.RATE(I).EQ.' ') GO TO 10
      DO 11 J=1,10
      IF (RATE(I).EQ.CHAR(J)) THEN
C

```

```

C      CONVERT THE SUBCOMPONENT RATINGS INTO INTEGER VALUES
C

```

```

      IRATE(I)=J-1
      GO TO 21
      ENDIF
11      CONTINUE

```

```

21      ISHIFT = 0
C
C      FOR EACH ELEMENT, SEARCH FOR THE FUZZY IMPT. FACTOR
C      CORR'S TO THE COND. RATING
C
DO 31 K=1,9,2
  IF (IRATE(I) .LE. K) THEN
    IFIF = K - ISHIFT
    IPOS = ILOC + I - 1
C
C      IFIF      = POSITION FUZZY IMPORTANCE FACTOR
C      IPOS      = POSITION OF ELEMENT
C      FUZZRATE  = FUZZY RATING
C      ICUT      = ALPHA LEVEL CUT
C      ALPVAL    = ALPHA SET
C
    DO 41 ICUT=1,9
      FUZZRATE(I,ICUT)=IRATE(I)-1+0.25*(ICUT-1)
41    ALPVAL(I,ICUT)=SIF(IPOS,IFIF,ICUT)
      GO TO 10
C
C      EXIT THIS LOOP - GET ANOTHER ELEMENT
C
    ENDIF
31    ISHIFT = ISHIFT + 1
C
C      RATING IS GREATER THAN K
C      REPEAT LOOP - VALUE OF K IS INCREASED BY 2
C
10    CONTINUE
C
C      THE FUZZY RATINGS REPRESENTED BY FUZZY NUMBERS AND
C      THE FUZZY IMPORTANCE FACTOR ASSOCIATED WITH EACH CONDITION
C      RATING HAVE BEEN FOUND.
C
      CALL ALPCALC(FUZZRATE,ALPVAL, NOEL)
C
C      COMBINE THE FIF AND FUZZY NUMBERS USING ALPCALC
C
      RETURN
      END
C
      SUBROUTINE ALPCALC(FUZZRATE,ALPVAL,NOEL)
      DIMENSION ALPVAL(20,9),FUZZRATE(20,9),FUZZSET(9)
      REAL NUME
      DO 10 I=1,9
C
C      FOR EACH DISCRETE ALPHA CUT POINT
C
        NUME=0.0
        DENO=0.0
C
C      NUME=NUMERATOR AND DENO=DENOMINATOR OF
C      FUZZY WEIGHTED AVERAGE EQUATION
C

```

```

DO 20 J=1,NOEL
NUME=ALPVAL(J,I)*FUZRATE(J,I) + NUME
DENO=ALPVAL(J,I) + DENO
C
C LOWER AND UPPER ALPHA LIMITS OF EACH FIF CORRESPOND
C TO THE LOWER AND UPPER LIMITS OF EACH FUZZY NUMBER.
C
20 CONTINUE
IF (NUME.NE.0.0 .AND. DENO.NE.0.0) THEN
FUZSET(I)=NUME/DENO
ELSE
FUZSET(I)=0.0
ENDIF
10 CONTINUE

CALL MAP(FUZSET,IFINAL)
C
C MAPPING OF THE RESULTANT FUZZY SET BACK TO CRISP RATING.
C
WRITE(*,100) IFINAL
100 FORMAT(10X,' COMPUTER RATING = ','[',I1,']')

RETURN
END

SUBROUTINE MAP(FUZSET,IFINAL)
DIMENSION FUZSET(9),D(2),DIST(2),RATE(2,9)

DMAX=100
DO 10 I=1,2
D(I)=0.0
DO 20 J=1,9
RATE(I,J)=(IFIX(FUZSET(5)+0.25)+I-2)-1+0.25*(J-1)
D(I)=D(I)+(FUZSET(J)-RATE(I,J))**2
20
C
C COMPUTE THE DISTANCE OF THE THREE CLOSEST FUZZY NUMBERS
C TO THE RESULTANT FUZZY SET
C
DIST(I)=SQRT(D(I))
IF (D(I) .LT. DMAX) THEN
DMAX=D(I)
C
C SELECT FUZZY NUMBER CLOSEST TO RESULTANT SET
C CHOOSE THE RATING WITH THE SMALLEST DIST.
C
IFINAL=INT(FUZSET(5)+0.25)+I-2
ENDIF
10 CONTINUE
RETURN
END

SUBROUTINE CLEAR
C
C CLEAR SCREEN

```

```

C      WRITE(*,10)
10     FORMAT(25(/))
      RETURN
      END

C
C      THIS SUBPROGRAM IS CALLED IDNO.FOR
C
C      SUBROUTINE ID(ISN)
C
C      SEARCH FOR BRIDGE STRUCTURE NUMBER IN EXISTING
C      DATABASE
C
C      CHARACTER XN(100)*15
C      CHARACTER ISN*20
C      CHARACTER N(34)*20
C      COMMON /BLK1/N
2      M=1
      WRITE(*,50)
      REWIND(1)
5      READ(1,10,END=99) (N(I), I=1,6)
C
C      IF END OF RECORD - GO TO 99
C
C      FORMAT(1X,A15,1X,A3,1X,A4,1X,A5,1X,A20,1X,A20,47(/))
10     READ ONLY THE FIRST LINE OF EACH BRIDGE RECORD
C
C      XN(M)=N(1)
      WRITE(*,40) M, XN(M)
C
C      PRINT BRIDGE STRUCTURE
C
C      M = M + 1
      GO TO 5
40     FORMAT(20X,I3, 14X, A15)
99     WRITE(*,'(//,15X,A\)' ) ' SELECT RECORD NUMBER -> '
      READ(*,*) J
      ISN= XN(J)
C
C      SELECT STRUCTURE NUMBER
C
C      IF (J.GT. M) GO TO 2
50     FORMAT(15X,'*****',
&      /,15X,'*          S T R U C T U R E      N U M B E R      *',
&      /,15X,'*          M O D U L E              *',
&      /,15X,'*****',
&      /,15X,'
&      /,15X,' RECORD NUMBER      STRUCTURE NUMBER      ',)

      END

C
C      THIS SUBPROGRAM IS CALLED STATX.FOR
C
C      SUBROUTINE STAT

```


C
C
C
PERFORM STATISTICAL ANALYSES

DIMENSION DAT1(500), DAT2(500)
 CHARACTER REM(90)*30,IPRT(90)*2
 CHARACTER ANS*2,COMP*40
 CHARACTER N(34)*20
 COMMON /BLK1/N
 COMMON /PRT/IPRT
 COMMON /MSG/REM

C
C
C
PRINT BRIDGE NO. < CONDITION

1 IFLAG=0
 IWW=100
 REWIND(1)
 DO 2 LL=1,IWW
 DAT2(LL)=0.0
 2 DAT1(LL)=0.0
 CALL CLEAR
 3 WRITE(*,110)
 WRITE(*,120)
 READ(*,'(A2)') ANS
 CALL ICHAR(ANS,NFLAG)
 IF (NFLAG .LE. 4) THEN
 4 WRITE(*,140)
 READ(*,'(A2)') ANS
 CALL ICHAR(ANS,MLVL)
 IF (MLVL .GT. 9 .OR. MLEVL .LT. 0) THEN
 CALL CLEAR
 WRITE(*,'(20X,A\)') ' INVALID RATING <0 9> -- TRY AGAIN '
 GO TO 4
 ENDIF
 CALL CLEAR
 WRITE(*,100)
 ELSE IF (NFLAG .EQ. 5) THEN

C
C
C
COMPUTE THE MEAN AND STD. DEVIATION

GO TO 5
 ELSE IF (NFLAG .EQ. 6) THEN
 RETURN
 ELSE
 WRITE(*,130)
 GO TO 3
 ENDIF

C
C
C
MLVL = MIN-LEVEL

MM=0
 NN=0
 5 READ(1,10, END=999) (N(I), I=1,6)
 6 FORMAT(1X,A15,1X,A3,1X,A4,1X,A5,1X,A20,1X,A20,3(/),)
 10 K=0
 DO 20 J=1,44
 READ(1,30) (IPRT(I+K),REM(I+K), I=1,2)
 20 K=K+2

30

```

FORMAT(1X,2(2X,A2,2X,A30))
  IF (NFLAG.EQ.1) THEN
    CALL ICHAR(IPRT(14),IDK)
    DAT1(NN+1)=IDK
    NN=NN+1
    IF (IDK.LE.MLVL) THEN
      IFLAG=1
      WRITE(*,40) N(1), IDK
      DAT2(MM+1)=IDK
      MM=MM+1
    ENDIF
  ELSE IF (NFLAG.EQ.2) THEN
    CALL ICHAR(IPRT(31),ISP)
    DAT1(NN+1)=ISP
    NN=NN+1
    IF (ISP.LE.MLVL) THEN
      IFLAG=1
      WRITE(*,50) N(1), ISP
      DAT2(MM+1)=ISP
      MM=MM+1
    ENDIF
  ELSE IF (NFLAG.EQ.3) THEN
    CALL ICHAR(IPRT(52),ISB)
    DAT1(NN+1)=ISB
    NN=NN+1
    IF (ISB.LE.MLVL) THEN
      IFLAG=1
      WRITE(*,60) N(1), ISB
      DAT2(MM+1)=ISB
      MM=MM+1
    ENDIF
  ELSE IF (NFLAG.EQ.4) THEN
    CALL ICHAR(IPRT(14),IDK)
    DAT1(NN+1)=IDK
    CALL ICHAR(IPRT(31),ISP)
    DAT1(NN+2)=ISP
    CALL ICHAR(IPRT(52),ISB)
    DAT1(NN+3)=ISB
    NN=NN+3
    IF (IDK.LE.MLVL.OR.ISP.LE.MLVL.OR.ISB.LE.MLVL) IFLAG=1
    IF (IDK .LE. MLVL) THEN
      WRITE (*,40) N(1), IDK
      DAT2(MM+1)=IDK
      MM=MM+1
    ENDIF
    IF (ISP .LE. MLVL) THEN
      WRITE (*,50) N(1), ISP
      DAT2(MM+1)=ISP
      MM=MM+1
    ENDIF
    IF (ISB .LE. MLVL) THEN
      WRITE (*,60) N(1), ISB
      DAT2(MM+1)=ISB
      MM=MM+1
    ENDIF
  ELSE IF (NFLAG.EQ.5) THEN

```

```

C      COMPUTE MEAN & STD. DEVIATION
C
      CALL ICHAR(IPRT(14),IDK)
      DAT1(NN+1)=IDK
      CALL ICHAR(IPRT(31),ISP)
      DAT1(NN+2)=ISP
      CALL ICHAR(IPRT(52),ISB)
      DAT1(NN+3)=ISB
      NN=NN+3
ENDIF
GO TO 6
999  IF (IFLAG.EQ.0.AND.NFLAG.NE.5) WRITE(*,210) MLVL
      IF (NFLAG.NE.5) THEN
        WRITE(*,200)
        READ(*,'(A)') A
        IF (MM.GT.3) THEN
          CALL MEAN (DAT2,MM,DMEAN)
          CALL STDEV(DAT2,MM,DMEAN,DSTDEV,DSTVAR)
          CALL MEDIAN (DAT2,MM,DMEDN,DMIN,DMAX)
          CALL COMTYPE(NFLAG,COMP)
          CALL CLEAR
          WRITE(*,180) MLVL
          WRITE(*,160) COMP,DMEAN,DMIN,DMAX,DMEDN,DSTVAR,DSTDEV
          WRITE(*,200)
          READ(*,'(A)') A
          ENDIF
        ENDIF
        IF (NN.GT.3) THEN
          CALL MEAN (DAT1,NN,DMEAN)
          CALL STDEV(DAT1,NN,DMEAN,DSTDEV,DSTVAR)
          CALL MEDIAN (DAT1,NN,DMEDN,DMIN,DMAX)
          CALL COMTYPE(NFLAG,COMP)
          CALL CLEAR
          WRITE(*,190)
          WRITE(*,160) COMP,DMEAN,DMIN,DMAX,DMEDN,DSTVAR,DSTDEV
          WRITE(*,200)
          READ(*,'(A)') A
          IWW=NN
          GO TO 1
        ELSE
          WRITE(*,220)
          GO TO 1
          CALL WAIT
        ENDIF
40    FORMAT(15X,A15,5X,'  DECK',5X,I2)
50    FORMAT(15X,A15,5X,'SUPERSTRUCTURE',5X,I2)
60    FORMAT(15X,A15,5X,'SUBSTRUCTURE',5X,I2)
80    FORMAT(//,12X,' >> END OF FILE << ',//)
100   FORMAT(15X,'*****',
&      /,15X,'*          C O N D I T I O N          *',
&      /,15X,'*****',
&      //,15X,' STRUCTURE NO: ',5X,' ELEMENT',5X,' RATING',/,)
110   FORMAT(15X,'*****',
&      /,15X,'*          S T A T I S T I C A L          *',
&      /,15X,'*          A N A L Y S I S          *',

```

```

&      /,15X,'*****'
&      /,15X,'*
&      /,15X,'*      1. DECK CONDITION ONLY      *
&      /,15X,'*      2. SUPERSTRUCTURE CONDITION ONLY      *
&      /,15X,'*      3. SUBSTRUCTURE CONDITION ONLY      *
&      /,15X,'*      4. DECK,SUPERSTRUCTURE & SUBSTRUCTURE      *
&      /,15X,'*      5. GENERAL STATISTICS      *
&      /,15X,'*      6. RETURN TO MAIN MENU      *
&      /,15X,'*
&      /,15X,'*****')
120  FORMAT(/,15X' SELECT OPTION --> '\)
130  FORMAT(/,15X,' INVALID OPTION ... RETRY  '/')
140  FORMAT(/,20X' +-----+
&      /,20X' | STATISTICAL ANALYSIS OF BRIDGES |
&      /,20X' | WITH CONDITION RATING LESS THAN |
&      /,20X' | OR EQUAL TO A CERTAIN LEVEL <0-9> |
&      /,20X' +-----+
&      /,20X' ENTER CONDITION RATING LEVEL--> ',\))

160  FORMAT(15X,'FOR ALL ',
&      /,25X, A40,
&      /,25X,'ELEMENTS IN THE DATABASE ',
&      /,15X,'
&      /,15X,' MEAN RATING = ',F5.2,
&      /,15X,' MINIMUM = ',F5.2,
&      /,15X,' MAXIMUM = ',F5.2,
&      /,15X,' MEDIAN = ',F5.2,
&      /,15X,' VARIANCE = ',F6.4,
&      /,15X,' STD DEVIATION = ',F6.4,
&      /,15X,'
&      /,15X,'*****')
180  FORMAT(15X,'*****'
&      /,15X,'* S T A T I S T I C S *
&      /,15X,'* A N A L Y S I S *
&      /,15X,'*****'
&      /,15X,'* OF RATINGS LESS THAN OR EQUAL TO',I2,7X,'*
&      /,15X,'*****')
190  FORMAT(15X,'*****'
&      /,15X,'* S T A T I S T I C S *
&      /,15X,'* A N A L Y S I S *
&      /,15X,'*****'
&      /,15X,'* OF ALL CONDITION RATINGS BETWEEN 0 AND 9 *
&      /,15X,'*****')
200  FORMAT(/,20X' +-----+
&      /,20X' | PRESS RETURN TO CONTINUE |
&      /,20X' +-----+\))

210  FORMAT(/,15X,
&      /,15X,' BRIDGE WITH ELEMENT RATING <',I2,' NOT FOUND ',
&      /,15X, //)

```

```

220      FORMAT(/,15X,
&          /,15X,' SAMPLE SIZE TOO SMALL FOR STATISTICAL ANALYSIS',
&          /,15X, //)

      RETURN
      END

      SUBROUTINE MEAN (X,N,XMEAN)
      DIMENSION X(N)
      SUM=0.0
      DO 10 I=1,N
          SUM=SUM+X(I)
10      CONTINUE
      XMEAN = SUM/FLOAT(N)
      RETURN
      END

      SUBROUTINE STDEV (X,N,XMEAN,XSTDEV,XVAR)
      DIMENSION X(N)
      SUMSQ=0.0
      DO 10 I=1,N
          XDIFX=X(I)-XMEAN
10      SUMSQ=SUMSQ+XDIFX*XDIFX

      XVAR=SUMSQ/FLOAT(N-1)
      XSTDEV=SQRT(XVAR)

      RETURN
      END

      SUBROUTINE MEDIAN (X,N,XMEDN,XMIN,XMAX)
      DIMENSION X(N)
      CALL SORTM(X,N)
      IF (MOD(N,2).EQ.0) THEN
          K=N/2
          XMEDN=(X(K)+X(K+1))/2.0
      ELSE
          K=(N+1)/2
          XMEDN=X(K)
      ENDIF
      XMIN=X(1)
      XMAX=X(N)
      RETURN
      END

      SUBROUTINE SORTM (X,N)
      DIMENSION X(N)

      IBOUND=N
      IXCH=0
50      DO 100 J=1,IBOUND-1
          IF(X(J).GT.X(J+1)) THEN
              TEMP=X(J)
              X(J)=X(J+1)
              X(J+1)=TEMP
              IXCH=J
          
```

```

      ENDIF
100  CONTINUE

      IF (IXCH.EQ. 0) RETURN
      IBOUND=IXCH
      GO TO 50
      RETURN
      END

      SUBROUTINE COMTYPE(N,COMP)
      CHARACTER COMP*40

      IF (N.EQ.1) COMP='DECK'
      IF (N.EQ.2) COMP='SUPERSTRUCTURE'
      IF (N.EQ.3) COMP='SUBSTRUCTURE'
      IF (N.EQ.4) COMP='DECK, SUPERSTRUCTURE & SUBSTRUCTURE'
      IF (N.EQ.5) COMP='DECK, SUPERSTRUCTURE & SUBSTRUCTURE'

      RETURN
      END

C
C      THIS SUBPROGRAM IS CALLED DBN.FOR
C

      SUBROUTINE DBNL

C
C      READ BRIDGE DATA BASE - PRINT NUMBER, CROSSING AND
C      LOCATION
C

      CHARACTER N(34)*20
      COMMON /BLK1/N
      MM=0
      REWIND(1)
      WRITE(*,50)
5      READ(1,10,END=999) (N(I), I=1,6)
C
C      END OF FILE GO TO FORMAT SPECIFIER 999
C
10     FORMAT(1X,A15,1X,A3,1X,A4,1X,A5,1X,A20,1X,A20,47(/),)
      WRITE(*,40) N(1), N(5), N(6)

C
C      N(1) = STRUCTURE NUMBER
C      N(5) = CROSSING RIVER OR ROAD INFORMATION
C      N(6) = LOCATION OF BRIDGE
C

      MM=MM+1
      IF (MM.EQ.15.OR.MM.EQ.30) THEN
      WRITE(*,*)
      WRITE(*,*) '          Pause.... Hit Return to Continue '
      READ(*,'(A)') A
      ENDIF
      GO TO 5
40     FORMAT(10X,A15, 5X, A20, 5X, A20)
50     FORMAT(15X,'*****',
&         /,15X,'*   S T R U C T U R E       L O C A T I O N   *',
&         /,15X,'*                               M O D U L E   *',
&         /,15X,'*****')

```

```

&      //,10X,' STRUCTURE ',15X,'CROSSING',15X, 'LOCATION ',
&      //,10X,' NUMBER ',)

```

```

999      WRITE(*,*)
        WRITE(*,1000)
1000     FORMAT(10X,' END OF RECORD ',//)
        CALL WAIT
        RETURN
        END

C
C      THIS SUBPROGRAM IS CALLED DEF.FOR
C
C      SUBROUTINE FINAL(MYRATE)
C
C      COMPONENT RATING ENTERED BY BRIDGE INSPECTOR
C
C      CHARACTER MYRATE*2
C      WRITE(*,'(1X,A\)' )' ENTER INSPECTOR`S CONDITION RATING ->'
C      READ (*,'(A2)' ) MYRATE
C      RETURN
C      END

C
C      SUBROUTINE RML(TYPE,MYRATE)
C
C      INFORMATION FOR REMAINING LIFE COMPUTATION
C
C      CHARACTER MYRATE*2,TYPE*4,SVC(10)*2
C      COMMON/SV/SVC
C      CALL POS(TYPE,LOC)
C      SVC(LOC)=MYRATE
C
C      SAVE COMPONENT RATING
C
C      RETURN
C      END

C
C      SUBROUTINE POS(TYPE,LOC)
C
C      LOCATION OF BRIDGE COMPONENT
C
C      CHARACTER TYPE*4
C
C      IF (TYPE.EQ.'DECK') LOC=1
C      IF (TYPE.EQ.'SUPS') LOC=2
C      IF (TYPE.EQ.'SUBS') LOC=3
C      IF (TYPE.EQ.'CHNL') LOC=4
C      IF (TYPE.EQ.'CULV') LOC=5
C      IF (TYPE.EQ.'APPR') LOC=6
C
C      RETURN
C      END

C
C      SUBROUTINE LOGIC(NOEL)
C
C      FOR RATING OF CHANNEL, CULVERT, APPROACH
C      COMBINATION OF FUZZY INFORMATION
C

```

```

DIMENSION ALPVAL(20,9),FUZRATE(20,9),IRATE(20)
CHARACTER RATE(20)*2, CHAR(10)*1
COMMON /NRT/RATE
DATA CHAR/'0','1','2','3','4','5','6','7','8','9'/
ITOP = 0
IBOT = 0
DO 5 I=1,NOEL
DO 5 J=1,9
FUZRATE(I,J)=0.1
5 ALPVAL(I,J)=0.0

DO 10 I=1,NOEL
IF (RATE(I).EQ.'-'.OR.RATE(I).EQ.' ') GO TO 10
DO 11 J=1,10
IF (RATE(I).EQ.CHAR(J)) THEN
IRATE(I)=J-1
GO TO 21
ENDIF
11 CONTINUE
21 ISHIFT = 0
DO 31 K=1,9,2
IF (IRATE(I) .LE. K) THEN
DO 41 ICUT=1,9
FUZRATE(I,ICUT)=IRATE(I)-1+0.25*(ICUT-1)
41 ALPVAL(I,ICUT)=IRATE(I)/10.0-IRATE(I)*.05
ENDIF
31 CONTINUE
10 CONTINUE

CALL ALPLGX(FUZRATE,ALPVAL, NOEL)

RETURN
END

SUBROUTINE ALPLGX(FUZRATE,ALPVAL,NOEL)
C
C FUZZY COMBINATION
C
DIMENSION ALPVAL(20,9),FUZRATE(20,9),FUZSET(9)
REAL NUME

DO 10 I=1,9
NUME=0.0
DENO=0.0
DO 20 J=1,NOEL
NUME=ALPVAL(J,I)*FUZRATE(J,I) + NUME
DENO=ALPVAL(J,I) + DENO
20 CONTINUE
IF (NUME.NE.0.0 .AND. DENO.NE.0.0) THEN
FUZSET(I)=NUME/DENO
ELSE
FUZSET(I)=0.0
ENDIF
10 CONTINUE

CALL MAPP(FUZSET,IFINAL)
C

```



```

C      MAPPING OF RESULTANT RATING TO NUMERICAL RATING
C
100  WRITE(*,100) IFINAL
      FORMAT(10X,'          COMPUTER RATING = ','[',I1,']')

      RETURN
      END

      SUBROUTINE MAPP(FUZSET,IFINAL)
      DIMENSION FUZSET(9),D(2),DIST(2),RATE(2,9)

      DMAX=100
      DO 10 I=1,2
      D(I)=0.0
      DO 20 J=1,9
      RATE(I,J)=(IFIX(FUZSET(5))+I-2)-1+0.25*(J-1)
      D(I)=D(I)+(FUZSET(J)-RATE(I,J))**2
20
C
C      COMPUTE THE DISTANCE OF THE THREE CLOSEST FUZZY NUMBERS
C      TO THE RESULTANT FUZZY SET
C
      DIST(I)=SQRT(D(I))
      IF (D(I) .LT. DMAX) THEN
      DMAX=D(I)

C
C      SELECT FUZZY NUMBER CLOSEST TO RESULTANT SET
C      CHOOSE THE RATING WITH THE SMALLEST DIST.
C
      IFINAL=INT(FUZSET(5))+I-2
      ENDIF

10  CONTINUE
      RETURN
      END

      SUBROUTINE JCHAR (ITEM,NOEL,I)

C
C      ENSURE SELECTED ELEMENT NUMBER IS VALID
C
      CHARACTER ITEM*2, CHAR(20)*2
      DATA CHAR/'1','2','3','4','5','6','7','8','9','10',
Z    '11','12','13','14','15','16','17','18','19','20' /
      I=NOEL+1
      DO 11 J=1,NOEL
      IF (ITEM .EQ. CHAR(J)) THEN
          I=J
          RETURN
      ENDIF
11  CONTINUE
      RETURN
      END

      SUBROUTINE DFCY

C
C      BRIDGE DEFICIENCIES RATING - INPUT DATA

```

```

C      CHARACTER RATE(20)*2, TYPE*4, ITEM*2
COMMON /NRT/RATE
TYPE='DEFY'
NOEL=6
C      CALL INTRO(TYPE)
10     CALL ELDEF(1000)
DO 40 I=1,NOEL
II=1000+I
20     CALL ELDEF(II)
READ(*,'(A2)') RATE(I)
IF (RATE(I).EQ.'n '.OR.RATE(I).EQ.'N ') THEN
C
C      ENTER MESSAGE
C
C      CALL MESSAGE(TYPE,I)
GO TO 20
ELSE IF (RATE(I).EQ.'h '.OR.RATE(I).EQ.'H ')THEN
CALL HELP(TYPE,I)
C
C      GET HELP
C
GO TO 20
ELSE IF (RATE(I).EQ.'u '.OR.RATE(I).EQ.'U ') THEN
C
C      UNDO ENTRY
C
IF((II-1).EQ.1000) GO TO 20
CALL ELDEF(II-1)
READ(*,'(A2)')RATE(I-1)
GO TO 20
ELSE IF (RATE(I).EQ.' '.OR.RATE(I).EQ.'- ') THEN
GO TO 40
ELSE
CALL ICHAR(RATE(I),J)
IF (J.LT.0 .OR. J.GT. 9) THEN
WRITE(*,99)
GO TO 20
ENDIF
ENDIF
40     CONTINUE
50     CALL CLEAR
CALL DHEAD
CALL SHOWDF
C
C      DISPLAY INFORMATION - CHECK FOR ERRORS
C
CALL BORDER
51     WRITE(*,'(1X,A\))') ' ARE THE RATINGS CORRECT ? <Y/N> '
READ(*,'(A)') ANS
IF (ANS.EQ.'N'.OR.ANS.EQ.'n')THEN
CALL CLEAR
CALL DHEAD
CALL SHOWDF
61     WRITE(*,'(1X,A\))') ' ENTER ITEM NO. '
READ(*,'(A)')ITEM
CALL JCHAR(ITEM,6,I)

```

```

      IF (I.LT.0 .OR. I.GT.NOEL) THEN
        CALL CLEAR
        CALL DHEAD
        CALL SHOWDF

```

```

      DISPLAY INFORMATION - CHECK FOR ERRORS

```

```

      WRITE(*,100)
      GO TO 61

```

```

    ENDIF

```

```

    WRITE(*,'(1X,A)') ' ENTER CORRECT VALUE or N=[REMARKS] '

```

```

    READ(*,'(A)')RATE(I)

```

```

    IF (RATE(I).EQ.'N'.OR.RATE(I).EQ.'n') CALL MESSAGE(TYPE,I)

```

```

    GO TO 50

```

```

  ELSE IF (ANS.EQ.'r'.OR.ANS.EQ.'R')THEN

```

```

    GO TO 10

```

```

  ELSE IF (ANS.EQ.'y'.OR.ANS.EQ.'Y')THEN

```

```

    CALL SAVE3(TYPE,NOEL)

```

```

    SAVE INFORMATION

```

```

    RETURN

```

```

  ELSE

```

```

    WRITE(*,*) '          SELECT Y=YES '

```

```

    WRITE(*,*) '          N=NO  '

```

```

    GO TO 51

```

```

  ENDIF

```

```

99    FORMAT(/,3X,'>> ENTER => N=[NOTES]  U=[UNDO]  H=[HELP]  -=[N/A]
& 0-9=[RATING] <<'/)
100   FORMAT(/,3X,'>> INVALID ITEM ... REPEAT << '/')
      RETURN
      END

```

```

SUBROUTINE DHEAD

```

```

DEFICIENCY APPRAISAL HEADER

```

```

WRITE(*,100)

```

```

100   FORMAT(15X '*****',
&      /,15X ' *                A P P R A I S A L                * ',
&      /,15X '*****',
&///)

```

```

      RETURN

```

```

      END

```

```

SUBROUTINE REMLIFE(IDK,ISP,ISB,LIFE)

```

```

COMPUTE REMAINING LIFE OF A BRIDGE

```

```

SEE TRB 1083 - PENNSYLVANIA BMS

```

```

LIFE=50
MLIFE=50
ISUM = IDK + ISP + ISB

```

C
C
C
C

```

SUM OF THE DECK, SUPERSTRUCTURE AND SUBSTRUCTURE
CONDITION

```

```

IF (ISUM .EQ. 27) THEN
  LIFE = 50
ELSE IF (ISUM .EQ. 26) THEN
  LIFE = 46
ELSE IF (ISUM .EQ. 25) THEN
  LIFE = 42
ELSE IF (ISUM .EQ. 24) THEN
  LIFE = 38
ELSE IF (ISUM .EQ. 23) THEN
  LIFE = 34
ELSE IF (ISUM .EQ. 22) THEN
  LIFE = 30
ELSE IF (ISUM .EQ. 21) THEN
  LIFE = 26
ELSE IF (ISUM .EQ. 20) THEN
  LIFE = 23
ELSE IF (ISUM .EQ. 19) THEN
  LIFE = 20
ELSE IF (ISUM .EQ. 18) THEN
  LIFE = 17
ELSE IF (ISUM .EQ. 17) THEN
  LIFE = 14
ELSE IF (ISUM .EQ. 16) THEN
  LIFE = 12
ELSE IF (ISUM .EQ. 15) THEN
  LIFE = 10
ELSE IF (ISUM .EQ. 14) THEN
  LIFE = 8
ELSE IF (ISUM .EQ. 13) THEN
  LIFE = 7
ELSE IF (ISUM .EQ. 12) THEN
  LIFE = 6
ELSE IF (ISUM .EQ. 11) THEN
  LIFE = 5
ELSE
  LIFE = 4
ENDIF
IF (ISP.LT.4.OR.ISB.LT.4) THEN
  IF (ISP .LE. ISB) THEN
    ICOND = ISP
  ELSE
    ICOND = ISB
  ENDIF
  IF (ICOND.EQ.4) THEN
    MLIFE=10
  ELSE IF (ICOND.EQ.3) THEN
    MLIFE=5
  ELSE IF (ICOND.EQ.2) THEN
    MLIFE=1

```

```

      ENDIF
      ELSE IF (IDK.LT.4) THEN
        MLIFE=10
      ENDIF
      IF (MLIFE .LE. LIFE) THEN
        LIFE = MLIFE
      ENDIF

```

```

      RETURN
    END

```

```

C
C   THIS SUBPROGRAM IS CALLED IMP.FOR
C

```

```

      SUBROUTINE SVCOND(TYPE,NOEL)

```

```

C
C   IMPROVEMENT ANALYSIS
C

```

```

      DIMENSION IM(50)
      CHARACTER TYPE*4, RATE(20)*2
      COMMON /NRT/RATE
      COMMON /PIM/IM
      CALL WHERE(TYPE,ILOC)

```

```

C
C   SEARCH FOR TYPE AND LOCATION
C

```

```

      DO 10 I=1,NOEL
      CALL ICHAR(RATE(I),JJ)
      IM(ILOC+I)=JJ
10    CONTINUE
      RETURN
      END

```

```

      SUBROUTINE WHERE(TYPE,LOC)

```

```

C
C   IMPROVEMENT FOR THE DECK, SUPERSTRUCTURE, AND
C   SUBSTRUCTURE ONLY
C

```

```

      CHARACTER TYPE*4
      IF (TYPE.EQ.'DECK') THEN
        LOC=0
      ELSE IF (TYPE.EQ.'SUPS') THEN
        LOC=13
      ELSE IF (TYPE.EQ.'SUBS') THEN
        LOC=29

```

```

      ENDIF
      RETURN
      END

```

```

      SUBROUTINE IMPROVE

```

```

C
C   IMPROVEMENT STRATEGIES
C

```

```

      DIMENSION IM(50)
      COMMON /PIM/IM

```

```

C      WRITE(*,99)
K=0
M=0
DO 10 I=1,49
IF (IM(I).GT.0.AND.IM(I).LT.4) THEN
M=M+1
IF (M.EQ.15.OR.M.EQ.30) THEN
WRITE(*,*)
WRITE(*,*) '           Pause.... Hit Return to Continue '
READ(*,'(A)') A
ENDIF
K=1
CALL PROPOSE(I)

C      PROPOSED IMPROVEMENT
C      GET IMPROVEMENT DATABASE
C      IMPROVEMENT FOR THE DECK, SUPERSTRUCTURE AND SUBSTRUCTURE
C
10    ENDIF
CONTINUE
IF (K .EQ. 0) THEN
WRITE(*,100)
ELSE
WRITE(*,101)
ENDIF
99    CALL WAIT
FORMAT(15X,' >>   I M P R O V E M E N T S       N E E D S   <<' //

C      MESSAGE TO THE BRIDGE INSPECTOR
C
C
100   FORMAT(///,20X,'
& /,11X,'
& /,11X,'               N O     I M P R O V E M E N T         I S
& /,11X,'                     N E E D E D
& /,11X,'
& /,11X,'
//

C      BRIDGE IN GOOD CONDITION
C
C
101   FORMAT(/,20X,'
& /,11X,' +-----+-----+-----+-----+
& /,11X,' | The above suggestions are some improvement needs
& /,11X,' | based on the condition of the various elements.
& /,11X,' | These suggestions are repair activities which may
& /,11X,' | require your attentions.
& /,11X,' +-----+-----+-----+-----+

RETURN
END

C      THIS SUBROUTINE IS CALLED HLP.FOR
C      IT CAN BE FURTHER EXPANDED TO INCLUDE
C      SUBCOMPONENT HELP GUIDELINES

```

```

C      SUBROUTINE HELP(TYPE,I)
C
C      HELP MODULE - CAN BE EXPANDED TO INCLUDE INSPECTION
C                   GUIDELINES
C
C      CHARACTER TYPE*4, ELMT*20
C
C      IF (TYPE.EQ.'DECK') THEN
C         ELMT='DECK'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'SUPS') THEN
C         ELMT='SUPERSTRUCTURE'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'SUBS') THEN
C         ELMT='SUBSTRUCTURE'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'CHNL') THEN
C         ELMT='CHANNEL'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'CULV') THEN
C         ELMT='CULVERT'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'APPR') THEN
C         ELMT='APPROACH ALIGNMENT'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'LOAD') THEN
C         ELMT='POSTED LOADING'
C         CALL TITLE(ELMT,I)
C         CALL SCHM1
C      ELSE IF (TYPE.EQ.'DEFY') THEN
C         ELMT='DEFICIENCY'
C         CALL TITLE(ELMT,I)
C         CALL SCHM2
C      ENDIF
C      RETURN
C      END
C
C      SUBROUTINE SCHM1
C
C      HELP - DEFINE THE BRIDGE RATING CODE DEFINITION
C            - FOR CONDITION RATING ONLY
C            - FEDERAL INSPECTION PLAN
C
C      WRITE(*,60)
C      FORMAT(15X,'*
60      &      /,15X,'*          CONDITION RATING
C      &      /,15X,'*          -----
C      &      /,15X,'*          RATING      DESCRIPTION
C      &      /,15X,'*          -----
C      &      /,15X,'*          9.          NEW CONDITION
C
C      *',
C      *',
C      *',
C      *',
C      *',
C      *',
C      *',

```

```

&      /,15X,'*      8.      GOOD CONDITION      '*'
&      /,15X,'*      7.      GENERALLY GOOD CONDITION      '*'
&      /,15X,'*      6.      FAIR CONDITION      '*'
&      /,15X,'*      5.      GENERALLY FAIR CONDITION      '*'
&      /,15X,'*      4.      MARGINAL CONDITION      '*'
&      /,15X,'*      3.      POOR CONDITION      '*'
&      /,15X,'*      2.      VERY POOR CONDITION      '*'
&      /,15X,'*      1.      CRITICAL CONDITION      '*'
&      /,15X,'*      0.      CLOSE FACILITY      '*'
&      /,15X,'*      '*'
&      /,15X,'*****')

```

RETURN

END

SUBROUTINE SCHM2

C
C
C
C

HELP - DEFINE THE BRIDGE RATING CODE DEFINITION
 - FOR APPRAISAL ONLY
 - FEDERAL INSPECTION PLAN

60

```

WRITE(*,60)
FORMAT(15X,'*
&      /,15X,'*      APPRAISAL RATING      '*'
&      /,15X,'*      -----      '*'
&      /,15X,'*      RATING      DESCRIPTION      '*'
&      /,15X,'*      -----      '*'
&      /,15X,'*      9.      CONDITION > DESIRABLE CRITERIA      '*'
&      /,15X,'*      8.      CONDITION = DESIRABLE CRITERIA      '*'
&      /,15X,'*      7.      CONDITION > MINIMUM CRITERIA      '*'
&      /,15X,'*      6.      CONDITION = MINIMUM CRITERIA      '*'
&      /,15X,'*      5.      CONDITION > MINIMUM ADEQUACY      '*'
&      /,15X,'*      4.      CONDITION = MINIMUM ADEQUACY      '*'
&      /,15X,'*      3.      CONDITION = INTOLERABLE (REPAIR)      '*'
&      /,15X,'*      2.      CONDITION = INTOLERABLE (REPLACE)      '*'
&      /,15X,'*      1.      IMMEDIATE REPAIR      '*'
&      /,15X,'*      0.      IMMEDIATE REPLACEMENT      '*'
&      /,15X,'*      '*'
&      /,15X,'*****')

```

RETURN

END

SUBROUTINE TITLE(TYPE,I)

C
C
C

HEADER

20

```

CHARACTER TYPE*20
CALL CLEAR
WRITE(*,20) TYPE, I
FORMAT(15X,'*****'
&      /,15X,'*      H E L P   M O D U L E      '*'
&      /,15X,'*****'
&      /,15X,'*      '*'
&      /,15X,'*      ',A20,'      '*'

```


& /,15X,'* ITEM NO: ',I2,6X,'

*')

RETURN
END

THIS SUBPROGRAM IS CALLED SAV.FOR
SUBROUTINE SAVE2(TYPE,NOEL,MYRATE)

SAVE NEW INFORMATION

CHARACTER SVRATE(90)*2, MYRATE*2
CHARACTER RATE(20)*2,TYPE*4
COMMON /NRT/RATE
COMMON /SRT/SVRATE
J=0
CALL POINTER(TYPE,LOC)
DO 10 I=1,NOEL
J=LOC+I
SVRATE(J)=RATE(I)
CONTINUE
SVRATE(J+1)=MYRATE
RETURN
END

SUBROUTINE SAVE3(TYPE,NOEL)

SAVE NEW INFORMATION

CHARACTER SVRATE(90)*2,TYPE*4
CHARACTER RATE(20)*2
COMMON /NRT/RATE
COMMON /SRT/SVRATE
J=0
CALL POINTER(TYPE,LOC)
DO 10 I=1,NOEL
J=LOC+I
SVRATE(J)=RATE(I)
CONTINUE
RETURN
END

SUBROUTINE POINTER(TYPE,LOC)

LOCATION OF EACH BRIDGE TYPE IN DATA FILE

CHARACTER TYPE*4
IF (TYPE.EQ.'DECK')THEN
LOC=0
ELSE IF (TYPE.EQ.'SUPS')THEN
LOC=14
ELSE IF (TYPE.EQ.'SUBS')THEN
LOC=31
ELSE IF (TYPE.EQ.'CHNL')THEN
LOC=52
ELSE IF (TYPE.EQ.'CULV')THEN
LOC=62

```

ELSE IF (TYPE.EQ.'APPR')THEN
    LOC=70
ELSE IF (TYPE.EQ.'LOAD')THEN
    LOC=77
ELSE IF (TYPE.EQ.'DEFY')THEN
    LOC=80
ENDIF
RETURN
END

```

SUBROUTINE STORE

```
STORE INFORMATION IN FILE
```

```

CHARACTER REM(90)*30
CHARACTER SVRATE(90)*2
COMMON /SRT/SVRATE
COMMON /MSG/REM

```

```

SVRATE = SAVE RATING
REM = SAVE REMARKS

```

```

K=0
DO 10 J=1,44
WRITE(2,20) (SVRATE(I+K), REM(I+K), I=1,2)
K=K+2
FORMAT(1X,2(2X,A2,2X,A30))
RETURN
END

```

SUBROUTINE MESSAGE(TYPE,I)

```
FOR RECORDING REMARKS
```

```

CHARACTER REM(90)*30, TYPE*4
COMMON /MSG/ REM
CALL POINTER(TYPE,LOC)

```

```
GET LOCATION OF BRIDGE ELEMENT
```

```

WRITE(*,*)'
WRITE(*,'(1X,A)')' ENTER REMARKS =>'
READ(*,'(A30)') REM(LOC+I)
RETURN
END

```

```

THIS SUBPROGRAM IS CALLED WRT.FOR
IT CAN BE FURTHER IMPROVED TO INCLUDE GRAPHIC INPUT
WINDOWS

```

SUBROUTINE MDECK(II)

```
FOR DECK SUBCOMPONENTS
```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

C
C
C

PRESENT COMPILER DOES NOT PERMIT FORMAT SPECIFIER
AS VARIABLE. EXAMPLE (WRITE*,II) NOT ALLOWED

```
IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(1)
IF (II.EQ.1002) WRITE(*,1002) IPRT(2)
IF (II.EQ.1003) WRITE(*,1003) IPRT(3)
IF (II.EQ.1004) WRITE(*,1004) IPRT(4)
IF (II.EQ.1005) WRITE(*,1005) IPRT(5)
IF (II.EQ.1006) WRITE(*,1006) IPRT(6)
IF (II.EQ.1007) WRITE(*,1007) IPRT(7)
IF (II.EQ.1008) WRITE(*,1008) IPRT(8)
IF (II.EQ.1009) WRITE(*,1009) IPRT(9)
IF (II.EQ.1010) WRITE(*,1010) IPRT(10)
IF (II.EQ.1011) WRITE(*,1011) IPRT(11)
IF (II.EQ.1012) WRITE(*,1012) IPRT(12)
IF (II.EQ.1013) WRITE(*,1013) IPRT(13)
```

```
1000  FORMAT(7X,10H  ITEM      ,10X,10H PREVIOUS ,12X,9H PRESENT
&      /,7X,10H  (58)      ,10X,10H  RATING  ,12X,8H RATING
&      /,7X,10H  -----,10X,10H  ----- ,12X,8H----- )

1001  FORMAT(2X,'1.  WEARING SURFACE      ',5X,[' ',A1,']'18X,'=>',\ )
1002  FORMAT(2X,'2.  DECK - STRUCTURAL    ',
&      /,2X,'          CONDITION      ',5X,[' ',A1,']'18X,'=>',\ )
1003  FORMAT(2X,'3.  CURBS                  ',5X,[' ',A1,']'18X,'=>',\ )
1004  FORMAT(2X,'4.  MEDIAN                  ',5X,[' ',A1,']'18X,'=>',\ )
1005  FORMAT(2X,'5.  SIDEWALKS              ',5X,[' ',A1,']'18X,'=>',\ )
1006  FORMAT(2X,'6.  PARAPET                ',5X,[' ',A1,']'18X,'=>',\ )
1007  FORMAT(2X,'7.  RAILING                ',5X,[' ',A1,']'18X,'=>',\ )
1008  FORMAT(2X,'8.  PAINT                  ',5X,[' ',A1,']'18X,'=>',\ )
1009  FORMAT(2X,'9.  DRAINS                 ',5X,[' ',A1,']'18X,'=>',\ )
1010  FORMAT(2X,'10. LIGHTING                ',5X,[' ',A1,']'18X,'=>',\ )
1011  FORMAT(2X,'11. UTILITIES               ',5X,[' ',A1,']'18X,'=>',\ )
1012  FORMAT(2X,'12. JOINT LEAKAGE           ',5X,[' ',A1,']'18X,'=>',\ )
1013  FORMAT(2X,'13. EXPANSION JOINTS        ',
&      /,2X,'          OR DEVICES      ',5X,[' ',A1,']'18X,'=>',\ )
```

RETURN
END

SUBROUTINE MSUP(II)

C
C
C

SUPERSTRUCTURE SUBCOMPONENTS

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```
IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(15)
IF (II.EQ.1002) WRITE(*,1002) IPRT(16)
IF (II.EQ.1003) WRITE(*,1003) IPRT(17)
IF (II.EQ.1004) WRITE(*,1004) IPRT(18)
IF (II.EQ.1005) WRITE(*,1005) IPRT(19)
IF (II.EQ.1006) WRITE(*,1006) IPRT(20)
IF (II.EQ.1007) WRITE(*,1007) IPRT(21)
IF (II.EQ.1008) WRITE(*,1008) IPRT(22)
```

```

IF (II.EQ.1009) WRITE(*,1009) IPRT(23)
IF (II.EQ.1010) WRITE(*,1010) IPRT(24)
IF (II.EQ.1011) WRITE(*,1011) IPRT(25)
IF (II.EQ.1012) WRITE(*,1012) IPRT(26)
IF (II.EQ.1013) WRITE(*,1013) IPRT(27)
IF (II.EQ.1014) WRITE(*,1014) IPRT(28)
IF (II.EQ.1015) WRITE(*,1015) IPRT(29)
IF (II.EQ.1016) WRITE(*,1016) IPRT(30)
1000 FORMAT(7X,10H ITEM ,10X,10H PREVIOUS ,12X,9H PRESENT
&      /,7X,10H (59) ,10X,10H RATING ,12X,8H RATING
&      /,7X,10H -----,10X,10H -----,12X,8H----- )
1001 FORMAT(2X,'1. BEARING DEVICES ',5X,[' ',A1,'] '18X,'=>',\))
1002 FORMAT(2X,'2. STRINGERS ',5X,[' ',A1,'] '18X,'=>',\))
1003 FORMAT(2X,'3. GIRDER,BEAMS,ARCH ',5X,[' ',A1,'] '18X,'=>',\))
1004 FORMAT(2X,'4. FLOOR BEAMS ',5X,[' ',A1,'] '18X,'=>',\))
1005 FORMAT(2X,'5. TRUSSES ',5X,[' ',A1,'] '18X,'=>',\))
1006 FORMAT(2X,'6. PAINT ',5X,[' ',A1,'] '18X,'=>',\))
1007 FORMAT(2X,'7. MACHINERY-movable ',5X,[' ',A1,'] '18X,'=>',\))
1008 FORMAT(2X,'8. RIVETS/BOLTS ',5X,[' ',A1,'] '18X,'=>',\))
1009 FORMAT(2X,'9. WELDS-CRACKS ',5X,[' ',A1,'] '18X,'=>',\))
1010 FORMAT(2X,'10. RUST ',5X,[' ',A1,'] '18X,'=>',\))
1011 FORMAT(2X,'11. TIMBER DECAY ',5X,[' ',A1,'] '18X,'=>',\))
1012 FORMAT(2X,'12. CONCRETE CRACKING ',5X,[' ',A1,'] '18X,'=>',\))
1013 FORMAT(2X,'13. COLLISION DAMAGE ',5X,[' ',A1,'] '18X,'=>',\))
1014 FORMAT(2X,'14. DEFLECTION-loaded ',5X,[' ',A1,'] '18X,'=>',\))
1015 FORMAT(2X,'15. ALIGNMENT-members ',5X,[' ',A1,'] '18X,'=>',\))
1016 FORMAT(2X,'16. VIBRATION-loaded ',5X,[' ',A1,'] '18X,'=>',\))

```

```

RETURN
END

```

```

SUBROUTINE MSUB(II)

```

```

C
C SUBSTRUCTURE SUBCOMPONENTS
C

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(32)
IF (II.EQ.1002) WRITE(*,1002) IPRT(33)
IF (II.EQ.1003) WRITE(*,1003) IPRT(34)
IF (II.EQ.1004) WRITE(*,1004) IPRT(35)
IF (II.EQ.1005) WRITE(*,1005) IPRT(36)
IF (II.EQ.1006) WRITE(*,1006) IPRT(37)
IF (II.EQ.1007) WRITE(*,1007) IPRT(38)
IF (II.EQ.1008) WRITE(*,1008) IPRT(39)
IF (II.EQ.1009) WRITE(*,1009) IPRT(40)
IF (II.EQ.1010) WRITE(*,1010) IPRT(41)
IF (II.EQ.1011) WRITE(*,1011) IPRT(42)
IF (II.EQ.1012) WRITE(*,1012) IPRT(43)
IF (II.EQ.1013) WRITE(*,1013) IPRT(44)
IF (II.EQ.1014) WRITE(*,1014) IPRT(45)
IF (II.EQ.1015) WRITE(*,1015) IPRT(46)
IF (II.EQ.1016) WRITE(*,1016) IPRT(47)
IF (II.EQ.1017) WRITE(*,1017) IPRT(48)
IF (II.EQ.1018) WRITE(*,1018) IPRT(49)

```

```

      IF (II.EQ.1019) WRITE(*,1019) IPRT(50)
      IF (II.EQ.1020) WRITE(*,1020) IPRT(51)
1000  FORMAT(7X,10H  ITEM      ,10X,10H PREVIOUS ,12X,9H PRESENT
      &      /,7X,10H  (60)    ,10X,10H RATING  ,12X,9H RATING
      &      /,7X,10H  -----,10X,10H ----- ,12X,8H----- )
1001  FORMAT(2X,'1.  ABUT-BRIDGE SEATS  ',5X,[' ',A1,']'18X,'=>',\ )
1002  FORMAT(2X,'2.  ABUT-WINGS         ',5X,[' ',A1,']'18X,'=>',\ )
1003  FORMAT(2X,'3.  ABUT-BACKWALL      ',5X,[' ',A1,']'18X,'=>',\ )
1004  FORMAT(2X,'4.  ABUT-FOOTING       ',5X,[' ',A1,']'18X,'=>',\ )
1005  FORMAT(2X,'5.  ABUT-PILES         ',5X,[' ',A1,']'18X,'=>',\ )
1006  FORMAT(2X,'6.  ABUT-EROSION       ',5X,[' ',A1,']'18X,'=>',\ )
1007  FORMAT(2X,'7.  ABUT-SETTLEMENT   ',5X,[' ',A1,']'18X,'=>',\ )
1008  FORMAT(2X,'8.  PIERS-CAPS         ',5X,[' ',A1,']'18X,'=>',\ )
1009  FORMAT(2X,'9.  PIERS-COLUMN      ',5X,[' ',A1,']'18X,'=>',\ )
1010  FORMAT(2X,'10. PIERS-FOOTING      ',5X,[' ',A1,']'18X,'=>',\ )
1011  FORMAT(2X,'11. PIERS-PILES       ',5X,[' ',A1,']'18X,'=>',\ )
1012  FORMAT(2X,'12. PIERS-SCOUR        ',5X,[' ',A1,']'18X,'=>',\ )
1013  FORMAT(2X,'13. PIERS-SETTLEMENT  ',5X,[' ',A1,']'18X,'=>',\ )
1014  FORMAT(2X,'14. PILE BENTS         ',5X,[' ',A1,']'18X,'=>',\ )
1015  FORMAT(2X,'15. CONC.CRACKS/SPALLS ',5X,[' ',A1,']'18X,'=>',\ )
1016  FORMAT(2X,'16. STEEL CORROSION    ',5X,[' ',A1,']'18X,'=>',\ )
1017  FORMAT(2X,'17. TIMBER DECAY      ',5X,[' ',A1,']'18X,'=>',\ )
1018  FORMAT(2X,'18. DEBRIS ON SEATS   ',5X,[' ',A1,']'18X,'=>',\ )
1019  FORMAT(2X,'19. PAINT             ',5X,[' ',A1,']'18X,'=>',\ )
1020  FORMAT(2X,'20. COLLISION DAMAGE  ',5X,[' ',A1,']'18X,'=>',\ )

```

```

RETURN
END

```

```

SUBROUTINE MCHNL(II)

```

C
C
C

```

CHANNEL ELEMENTS

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

      IF (II.LE.1000) WRITE(*,1000)
      IF (II.EQ.1001) WRITE(*,1001) IPRT(53)
      IF (II.EQ.1002) WRITE(*,1002) IPRT(54)
      IF (II.EQ.1003) WRITE(*,1003) IPRT(55)
      IF (II.EQ.1004) WRITE(*,1004) IPRT(56)
      IF (II.EQ.1005) WRITE(*,1005) IPRT(57)
      IF (II.EQ.1006) WRITE(*,1006) IPRT(58)
      IF (II.EQ.1007) WRITE(*,1007) IPRT(59)
      IF (II.EQ.1008) WRITE(*,1008) IPRT(60)
      IF (II.EQ.1009) WRITE(*,1009) IPRT(61)
1000  FORMAT(7X,10H  ITEM      ,10X,10H PREVIOUS ,12X,9H PRESENT
      &      /,7X,10H  (61)    ,10X,10H RATING  ,12X,8H RATING
      &      /,7X,10H  -----,10X,10H ----- ,12X,8H----- )
1001  FORMAT(2X,'1.  CHANNEL SCOUR      ',5X,[' ',A1,']'18X,'=>',\ )
1002  FORMAT(2X,'2.  EMBANKMENT EROSION ',5X,[' ',A1,']'18X,'=>',\ )
1003  FORMAT(2X,'3.  DRIFT              ',5X,[' ',A1,']'18X,'=>',\ )
1004  FORMAT(2X,'4.  VEGETATION         ',5X,[' ',A1,']'18X,'=>',\ )
1005  FORMAT(2X,'5.  CHANNEL CHANGE     ',5X,[' ',A1,']'18X,'=>',\ )
1006  FORMAT(2X,'6.  FENDER SYSTEM      ',5X,[' ',A1,']'18X,'=>',\ )

```

```

1007     FORMAT(2X,'7.  SPUR DIKES/JETTIES ',5X,[' ',A1,']'18X,'=>',\)\
1008     FORMAT(2X,'8.  RIP RAP ',5X,[' ',A1,']'18X,'=>',\)\
1009     FORMAT(2X,'9.  ADEQUACY OF OPENING',5X,[' ',A1,']'18X,'=>',\)\

```

```

RETURN
END

```

```

SUBROUTINE MCULV(II)

```

```

C
C
C

```

```

CULVERT ELEMENTS

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(63)
IF (II.EQ.1002) WRITE(*,1002) IPRT(64)
IF (II.EQ.1003) WRITE(*,1003) IPRT(65)
IF (II.EQ.1004) WRITE(*,1004) IPRT(66)
IF (II.EQ.1005) WRITE(*,1005) IPRT(67)
IF (II.EQ.1006) WRITE(*,1006) IPRT(68)
IF (II.EQ.1007) WRITE(*,1007) IPRT(69)
1000   FORMAT(7X,10H  ITEM      ,10X,10H PREVIOUS ,12X,9H PRESENT
&      /,7X,10H  (62)      ,10X,10H RATING  ,12X,8H RATING
&      /,7X,10H  -----,10X,10H ----- ,12X,8H----- )

1001   FORMAT(2X,'1.  BARREL-CONCRETE ',5X,[' ',A1,']'18X,'=>',\)\
1002   FORMAT(2X,'2.  BARREL-STEEL   ',5X,[' ',A1,']'18X,'=>',\)\
1003   FORMAT(2X,'3.  BARREL-TIMBER  ',5X,[' ',A1,']'18X,'=>',\)\
1004   FORMAT(2X,'4.  HEADWALL       ',5X,[' ',A1,']'18X,'=>',\)\
1005   FORMAT(2X,'5.  CUTOFF WALL    ',5X,[' ',A1,']'18X,'=>',\)\
1006   FORMAT(2X,'6.  ADEQUACY      ',5X,[' ',A1,']'18X,'=>',\)\
1007   FORMAT(2X,'7.  DEBRIS        ',5X,[' ',A1,']'18X,'=>',\)\

```

```

RETURN
END

```

```

SUBROUTINE MAPPR(II)

```

```

C
C
C

```

```

APPROACH ELEMENTS

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(71)
IF (II.EQ.1002) WRITE(*,1002) IPRT(72)
IF (II.EQ.1003) WRITE(*,1003) IPRT(73)
IF (II.EQ.1004) WRITE(*,1004) IPRT(74)
IF (II.EQ.1005) WRITE(*,1005) IPRT(75)
IF (II.EQ.1006) WRITE(*,1006) IPRT(76)
1000   FORMAT(7X,10H  ITEM      ,10X,10H PREVIOUS ,12X,9H PRESENT
&      /,7X,10H  (65)      ,10X,10H RATING  ,12X,8H RATING
&      /,7X,10H  -----,10X,10H ----- ,12X,8H----- )

1001   FORMAT(2X,'1.  ALIGNMENT      ',5X,[' ',A1,']'18X,'=>',\)\

```

```

1002     FORMAT(2X,'2.  APPROACH SLAB           ',5X,[' ',A1,']'18X,'=>',\ )
1003     FORMAT(2X,'3.  RELIEF JOINTS           ',5X,[' ',A1,']'18X,'=>',\ )
1004     FORMAT(2X,'4.  APPROACH-GUARDRAIL      ',5X,[' ',A1,']'18X,'=>',\ )
1005     FORMAT(2X,'5.  APPROACH-PAVEMENT       ',5X,[' ',A1,']'18X,'=>',\ )
1006     FORMAT(2X,'6.  APPROACH-EMBANKMENT     ',5X,[' ',A1,']'18X,'=>',\ )

```

```

RETURN
END

```

```

SUBROUTINE MLOAD(II)

```

```

C
C
C

```

```

POSTED LOADINGS

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(78)
IF (II.EQ.1002) WRITE(*,1002) IPRT(79)
IF (II.EQ.1003) WRITE(*,1003) IPRT(80)
1000  FORMAT(7X,10H  ITEM      ,10X,10H  PREVIOUS ,12X,9H  PRESENT
      &      /,7X,10H  (66)    ,10X,10H  RATING  ,12X,8H  RATING
      &      /,7X,10H  -----,10X,10H  ----- ,12X,8H----- )

1001  FORMAT(2X,'1.  POSTED LOADING           ',5X,[' ',A1,']'18X,'=>',\ )
1002  FORMAT(2X,'2.  LEGIBILITY               ',5X,[' ',A1,']'18X,'=>',\ )
1003  FORMAT(2X,'3.  VISIBILITY               ',5X,[' ',A1,']'18X,'=>',\ )

```

```

RETURN
END

```

```

SUBROUTINE SHOWDK

```

```

C
C
C

```

```

DISPLAY DECK INFORMATION

```

```

CHARACTER IPRT(90)*2
CHARACTER RATE(20)*2, REM(90)*30
COMMON /NRT/RATE
COMMON /MSG/REM
COMMON /PRT/IPRT
CALL CLEAR
WRITE(*,99)
CALL BORDER

```

```

C
C
C
C
C

```

```

IPRT  = PREVIOUS RATING
RATE  = PRESENT RATING
REM   = REMARKS

```

```

WRITE(*,100)
WRITE(*,101) IPRT(1),RATE(1),REM(1)
WRITE(*,102) IPRT(2),RATE(2),REM(2)
WRITE(*,103) IPRT(3),RATE(3),REM(3)
WRITE(*,104) IPRT(4),RATE(4),REM(4)

```



```

WRITE(*,105) IPRT(5),RATE(5),REM(5)
WRITE(*,106) IPRT(6),RATE(6),REM(6)
WRITE(*,107) IPRT(7),RATE(7),REM(7)
WRITE(*,108) IPRT(8),RATE(8),REM(8)
WRITE(*,109) IPRT(9),RATE(9),REM(9)
WRITE(*,110) IPRT(10),RATE(10),REM(10)
WRITE(*,111) IPRT(11),RATE(11),REM(11)
WRITE(*,112) IPRT(12),RATE(12),REM(12)
WRITE(*,113) IPRT(13),RATE(13),REM(13)
WRITE(*,*) ' ----- '
WRITE(*,114) IPRT(14)
CALL COMPUTE(13,1)
CALL BORDER
99  FORMAT(25X,20H CONDITION RATING )
100 FORMAT(5X,10H DECK (58),10X,5HOLD ,3X,5HNEW
&      /,5X,10H CONDITION,10X,5HDATA ,3X,5HDATA ,10X,9H REMARKS
&      /,5X,10H -----,10X,5H----- ,3X,5H----- ,10X,9H -----)
101  FORMAT(2X,'1.  WEARING SURFACE ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
102  FORMAT(2X,'2.  DECK - STRUCTURAL',
&      /,2X,'          CONDITION ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
103  FORMAT(2X,'3.  CURBS          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
104  FORMAT(2X,'4.  MEDIAN          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
105  FORMAT(2X,'5.  SIDEWALKS      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
106  FORMAT(2X,'6.  PARAPET        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
107  FORMAT(2X,'7.  RAILING        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
108  FORMAT(2X,'8.  PAINT          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
109  FORMAT(2X,'9.  DRAINS          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
110  FORMAT(2X,'10. LIGHTING        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
111  FORMAT(2X,'11. UTILITIES       ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
112  FORMAT(2X,'12. JOINT LEAKAGE   ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
113  FORMAT(2X,'13. EXPANSION JOINTS ',
&      /,2X,'          OR DEVICES ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&> ',A30)
114  FORMAT(2X,'PREVIOUS DECK RATING ',2X,[' ',A1,'])
      RETURN
      END

SUBROUTINE SHOWSP

C
C  DISPLAY SUPERSTRUCTURE INFORMATION
C

CHARACTER IPRT(90)*2
CHARACTER RATE(20)*2, REM(90)*30
COMMON /NRT/RATE
COMMON /MSG/REM

```



```
COMMON /PRT/IPRT
CALL CLEAR
WRITE(*,99)
CALL BORDER
```

```
IPRT = PREVIOUS RATING
RATE = PRESENT RATING
REM = REMARKS
```

```
WRITE(*,100)
WRITE(*,101) IPRT(15),RATE(1),REM(15)
WRITE(*,102) IPRT(16),RATE(2),REM(16)
WRITE(*,103) IPRT(17),RATE(3),REM(17)
WRITE(*,104) IPRT(18),RATE(4),REM(18)
WRITE(*,105) IPRT(19),RATE(5),REM(19)
WRITE(*,106) IPRT(20),RATE(6),REM(20)
WRITE(*,107) IPRT(21),RATE(7),REM(21)
WRITE(*,108) IPRT(22),RATE(8),REM(22)
WRITE(*,109) IPRT(23),RATE(9),REM(23)
WRITE(*,110) IPRT(24),RATE(10),REM(24)
WRITE(*,111) IPRT(25),RATE(11),REM(25)
WRITE(*,112) IPRT(26),RATE(12),REM(26)
WRITE(*,113) IPRT(27),RATE(13),REM(27)
WRITE(*,114) IPRT(28),RATE(14),REM(28)
WRITE(*,115) IPRT(29),RATE(15),REM(29)
WRITE(*,116) IPRT(30),RATE(16),REM(30)
```

```
WRITE(*,*) ' ----- '
```

```
WRITE(*,117) IPRT(31)
```

```
CALL COMPUTE(16,14)
```

```
CALL BORDER
```

```
99  FORMAT(25X,20H CONDITION RATING )
100  FORMAT(5X,10H SUPER(59),10X,5HOLD ,3X,5HNEW
    &    /,5X,10H STRUCTURE,10X,5HDATA ,3X,5HDATA ,10X,9H REMARKS
    &    /,5X,10H -----,10X,5H---- ,3X,5H---- ,10X,9H ----- )
101  FORMAT(2X,'1. BEARING DEVICES ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
102  FORMAT(2X,'2. STRINGERS ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
103  FORMAT(2X,'3. GIRDER/BEAMS/ARCH',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
104  FORMAT(2X,'4. FLOOR BEAMS ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
105  FORMAT(2X,'5. TRUSSES ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
106  FORMAT(2X,'6. PAINT ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
107  FORMAT(2X,'7. MACHINERY ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
108  FORMAT(2X,'8. RIVETS/BOLTS ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
109  FORMAT(2X,'9. WELDS-CRACKS ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
110  FORMAT(2X,'10. RUST ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
111  FORMAT(2X,'11. TIMBER DECAY ',2X,['',A1,']'5X,['',A1,']',3X,
    &'> ',A30)
112  FORMAT(2X,'12. CONCRETE CRACKING',2X,['',A1,']'5X,['',A1,']',3X,
```

```

&'> ',A30)
113   FORMAT(2X,'13. COLLISION DAMAGE ',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)
114   FORMAT(2X,'14. DEFLECTION          ',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)
115   FORMAT(2X,'15. ALIGNMENT          ',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)
116   FORMAT(2X,'16. VIBRATION          ',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)
117   FORMAT(2X,'PREV.SUPERSTR. RATING',2X,['',A1,']')
      RETURN
      END

```

SUBROUTINE SHOWSB

```

C
C   DISPLAY SUBSTRUCTURE INFORMATION
C

```

```

      CHARACTER IPRT(90)*2
      CHARACTER RATE(20)*2, REM(90)*30
      COMMON /NRT/RATE
      COMMON /MSG/REM
      COMMON /PRT/IPRT

```

```

C
C   IPRT  = PREVIOUS RATING
C   RATE  = PRESENT RATING
C   REM   = REMARKS
C

```

```

      WRITE(*,100)
      WRITE(*,101) IPRT(32),RATE(1),REM(32)
      WRITE(*,102) IPRT(33),RATE(2),REM(33)
      WRITE(*,103) IPRT(34),RATE(3),REM(34)
      WRITE(*,104) IPRT(35),RATE(4),REM(35)
      WRITE(*,105) IPRT(36),RATE(5),REM(36)
      WRITE(*,106) IPRT(37),RATE(6),REM(37)
      WRITE(*,107) IPRT(38),RATE(7),REM(38)
      WRITE(*,108) IPRT(39),RATE(8),REM(39)
      WRITE(*,109) IPRT(40),RATE(9),REM(40)
      WRITE(*,110) IPRT(41),RATE(10),REM(41)
      WRITE(*,111) IPRT(42),RATE(11),REM(42)
      WRITE(*,112) IPRT(43),RATE(12),REM(43)
      WRITE(*,113) IPRT(44),RATE(13),REM(44)
      WRITE(*,114) IPRT(45),RATE(14),REM(45)
      WRITE(*,115) IPRT(46),RATE(15),REM(46)
      WRITE(*,116) IPRT(47),RATE(16),REM(47)
      WRITE(*,117) IPRT(48),RATE(17),REM(48)
      WRITE(*,118) IPRT(49),RATE(18),REM(49)
      WRITE(*,119) IPRT(50),RATE(19),REM(50)
      WRITE(*,120) IPRT(51),RATE(20),REM(51)
      CALL BORDER
      WRITE(*,121) IPRT(52)
      CALL COMPUTE(20,40)

```

```

100   FORMAT(2X,' SUBSTRUCTURE (60)',5X,5HOLD ,3X,5HNEW ,10X,' REI
&ARKS ')
101   FORMAT(2X,'1. ABUT-BRIDGE SEATS',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)
102   FORMAT(2X,'2. ABUT-WINGS          ',2X,['',A1,']'5X,['',A1,']',3X,
&'> ',A30)

```

```

103     FORMAT(2X,'3.  ABUT-BACKWALL      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
104     FORMAT(2X,'4.  ABUT-FOOTING      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
105     FORMAT(2X,'5.  ABUT-PILES        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
106     FORMAT(2X,'6.  ABUT-EROSION      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
107     FORMAT(2X,'7.  ABUT-SETTLEMENT   ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
108     FORMAT(2X,'8.  PIERS-CAPS        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
109     FORMAT(2X,'9.  PIERS-COLUMN      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
110     FORMAT(2X,'10. PIERS-FOOTING     ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
111     FORMAT(2X,'11. PIERS-PILES       ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
112     FORMAT(2X,'12. PIERS-SCOUR       ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
113     FORMAT(2X,'13. PIERS-SETTLEMENT  ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
114     FORMAT(2X,'14. PILE BENTS        ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
115     FORMAT(2X,'15. CRACKS/SPALLS     ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
116     FORMAT(2X,'16. STEEL CORROSION   ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
117     FORMAT(2X,'17. TIMBER DECAY      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
118     FORMAT(2X,'18. DEBRIS ON SEATS   ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
119     FORMAT(2X,'19. PAINT              ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
120     FORMAT(2X,'20. COLLISION DAMAGE  ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
121     FORMAT(2X,'PREV.SUBSTRUC. RATING',2X,[' ',A1,']')
      RETURN
      END

```

SUBROUTINE SHOWCH

```

C
C     SHOW CHANNEL INFORMATION
C
      CHARACTER IPRT(90)*2
      CHARACTER RATE(20)*2, REM(90)*30
      COMMON /NRT/RATE
      COMMON /MSG/REM
      COMMON /PRT/IPRT
      CALL CLEAR
      WRITE(*,99)
      CALL BORDER

```

```

C
C     IPRT  = PREVIOUS RATING
C     RATE  = PRESENT RATING
C     REM   = REMARKS
C

```

```

WRITE(*,100)
WRITE(*,101) IPRT(53),RATE(1),REM(53)
WRITE(*,102) IPRT(54),RATE(2),REM(54)
WRITE(*,103) IPRT(55),RATE(3),REM(55)
WRITE(*,104) IPRT(56),RATE(4),REM(56)
WRITE(*,105) IPRT(57),RATE(5),REM(57)
WRITE(*,106) IPRT(58),RATE(6),REM(58)
WRITE(*,107) IPRT(59),RATE(7),REM(59)
WRITE(*,108) IPRT(60),RATE(8),REM(60)
WRITE(*,109) IPRT(61),RATE(9),REM(61)
WRITE(*,*) ' -----'
WRITE(*,110) IPRT(62)
CALL LOGIC(9)
CALL BORDER
99  FORMAT(25X,20H CONDITION RATING      )
100  FORMAT(4X,13H CHANNEL (61),8X,5HOLD  ,3X,5HNEW
&    /,4X,13H PROTECTION  ,8X,5HDATA  ,3X,5HDATA  ,10X,8H REMARKS
&    /,4X,13H -----,8X,5H---- ,3X,5H---- ,10X,8H -----)
101  FORMAT(2X,'1. CHANNEL SCOUR      ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
102  FORMAT(2X,'2. EMBANKMENT EROSION',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
103  FORMAT(2X,'3. DRIFT              ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
104  FORMAT(2X,'4. VEGETATION         ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
105  FORMAT(2X,'5. CHANNEL CHANGE    ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
106  FORMAT(2X,'6. FENDER SYSTEM      ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
107  FORMAT(2X,'7. SPUR DIKES/JETTIES',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
108  FORMAT(2X,'8. RIP RAP            ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
109  FORMAT(2X,'9. OPENING ADEQUACY   ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
110  FORMAT(2X,'PREV. CHANNEL RATING ',2X,['A1,'])

RETURN
END

SUBROUTINE SHOWCV
C
C  SHOW CULVERT INFORMATION
C

CHARACTER IPRT(90)*2
CHARACTER RATE(20)*2, REM(90)*30
COMMON /NRT/RATE
COMMON /MSG/REM
COMMON /PRT/IPRT
CALL CLEAR
WRITE(*,99)
CALL BORDER
C

```

```

C      IPRT  = PREVIOUS RATING
C      RATE  = PRESENT RATING
C      REM   = REMARKS
C
      WRITE(*,100)
      WRITE(*,101) IPRT(63),RATE(1),REM(63)
      WRITE(*,102) IPRT(64),RATE(2),REM(64)
      WRITE(*,103) IPRT(65),RATE(3),REM(65)
      WRITE(*,104) IPRT(66),RATE(4),REM(66)
      WRITE(*,105) IPRT(67),RATE(5),REM(67)
      WRITE(*,106) IPRT(68),RATE(6),REM(68)
      WRITE(*,107) IPRT(69),RATE(7),REM(69)
      WRITE(*,*) ' ----- '
      WRITE(*,108) IPRT(70)
      CALL LOGIC(7)
      CALL BORDER
99     FORMAT(25X,20H CONDITION RATING          )
100    FORMAT(4X,13H CULVERT (62),8X,5HOLD      ,3X,5HNEW
&      /,4X,13H RETAIN.WALLS,8X,5HDATA      ,3X,5HDATA ,10X,8H REMARKS
&      /,4X,13H -----,8X,5H-----,3X,5H-----,10X,8H -----)
101    FORMAT(2X,'1. BARREL-CONCRETE      ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
102    FORMAT(2X,'2. BARREL-STEEL          ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
103    FORMAT(2X,'3. BARREL-TIMBER         ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
104    FORMAT(2X,'4. HEADWALL              ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
105    FORMAT(2X,'5. CUTOFF WALL           ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
106    FORMAT(2X,'6. ADEQUACY              ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
107    FORMAT(2X,'7. DEBRIS                ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
108    FORMAT(2X,'PREV. CULVERT RATING ',2X,['A1,'])

      RETURN
      END

      SUBROUTINE SHOWAP

C      SHOW APPROACH INFORMATION
C
      CHARACTER IPRT(90)*2
      CHARACTER RATE(20)*2, REM(90)*30
      COMMON /NRT/RATE
      COMMON /MSG/REM
      COMMON /PRT/IPRT
      CALL CLEAR
      WRITE(*,99)
      CALL BORDER

C      IPRT  = PREVIOUS RATING
C      RATE  = PRESENT RATING
C      REM   = REMARKS
C
      WRITE(*,100)

```

```

WRITE(*,101) IPRT(71),RATE(1),REM(71)
WRITE(*,102) IPRT(72),RATE(2),REM(72)
WRITE(*,103) IPRT(73),RATE(3),REM(73)
WRITE(*,104) IPRT(74),RATE(4),REM(74)
WRITE(*,105) IPRT(75),RATE(5),REM(75)
WRITE(*,106) IPRT(76),RATE(6),REM(76)
WRITE(*,*) ' ----- '
WRITE(*,107) IPRT(77)
CALL LOGIC(6)
CALL BORDER
99  FORMAT(25X,20H CONDITION RATING          )
100  FORMAT(4X,13H APPROACH 65 ,8X,5HOLD    ,3X,5HNEW
&    /,4X,13H ALIGNMENT    ,8X,5HDATA    ,3X,5HDATA ,10X,8H REMARKS
&    /,4X,13H -----,8X,5H----- ,3X,5H----- ,10X,8H -----)
101  FORMAT(2X,'1.ALIGNMENT          ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
102  FORMAT(2X,'2.APPROACH SLAB          ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
103  FORMAT(2X,'3.RELIEF JOINTS          ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
104  FORMAT(2X,'4.APPROACH-GUARDRAIL ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
105  FORMAT(2X,'5.APPROACH-PAVEMENT ',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
106  FORMAT(2X,'6.APPROACH-EMBANKMENT',2X,['A1,']'5X,['A1,'],'3X,
&'> ',A30)
107  FORMAT(2X,'PREV.APPROACH RATING ',2X,['A1,'])

RETURN
END

SUBROUTINE SHOWLD

C
C  SHOW LOADING
C

CHARACTER IPRT(90)*2
CHARACTER RATE(20)*2, REM(90)*30
COMMON /NRT/RATE
COMMON /MSG/REM
COMMON /PRT/IPRT
CALL CLEAR
WRITE(*,99)
CALL BORDER

C
C  IPRT  = PREVIOUS RATING
C  RATE  = PRESENT RATING
C  REM   = REMARKS
C

WRITE(*,100)
WRITE(*,101) IPRT(78),RATE(1),REM(78)
WRITE(*,102) IPRT(79),RATE(2),REM(79)
WRITE(*,103) IPRT(80),RATE(3),REM(80)
CALL BORDER
99  FORMAT(25X,20H CONDITION RATING          )
100  FORMAT(4X,13H POSTED (66) ,8X,5HOLD    ,3X,5HNEW
&    /,4X,13H LOADING    ,8X,5HDATA    ,3X,5HDATA ,10X,8H REMARKS
&    /,4X,13H -----,8X,5H----- ,3X,5H----- ,10X,8H -----)

```



```

101     FORMAT(2X,'1. POSTED LOADING      ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
102     FORMAT(2X,'2. LEGIBILITY          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
103     FORMAT(2X,'3. VISIBILITY          ',2X,[' ',A1,']'5X,[' ',A1,']',3X,
&'> ',A30)
      RETURN
      END

```

SUBROUTINE ENTRY(I)

ENTER GENDATA INFORMATION

```

      IF (I.EQ.1) WRITE(*,1)
      IF (I.EQ.2) WRITE(*,2)
      IF (I.EQ.3) WRITE(*,3)
      IF (I.EQ.4) WRITE(*,4)
      IF (I.EQ.5) WRITE(*,5)
      IF (I.EQ.6) WRITE(*,6)
      IF (I.EQ.7) WRITE(*,7)
      IF (I.EQ.8) WRITE(*,8)
      IF (I.EQ.9) WRITE(*,9)
      IF (I.EQ.10) WRITE(*,10)
      IF (I.EQ.11) WRITE(*,11)
      IF (I.EQ.12) WRITE(*,12)
      IF (I.EQ.13) WRITE(*,13)
      IF (I.EQ.14) WRITE(*,14)
      IF (I.EQ.15) WRITE(*,15)
      IF (I.EQ.16) WRITE(*,16)
      IF (I.EQ.17) WRITE(*,17)
      IF (I.EQ.18) WRITE(*,18)
      IF (I.EQ.19) WRITE(*,19)
      IF (I.EQ.20) WRITE(*,20)
      IF (I.EQ.21) WRITE(*,21)
      IF (I.EQ.22) WRITE(*,22)
      IF (I.EQ.23) WRITE(*,23)
      IF (I.EQ.24) WRITE(*,24)
      IF (I.EQ.25) WRITE(*,25)
      IF (I.EQ.26) WRITE(*,26)
      IF (I.EQ.27) WRITE(*,27)
      IF (I.EQ.28) WRITE(*,28)
      IF (I.EQ.29) WRITE(*,29)
      IF (I.EQ.30) WRITE(*,30)
      IF (I.EQ.31) WRITE(*,31)
      IF (I.EQ.32) WRITE(*,32)
      IF (I.EQ.33) WRITE(*,33)
      IF (I.EQ.34) WRITE(*,34)

```

```

1     FORMAT(2X,' 1  ENTER STRUCTURE NO:      => ',\ )
2     FORMAT(2X,' 2  ENTER DISTRICT NO:       => ',\ )
3     FORMAT(2X,' 3  ENTER COUNTY NO:         => ',\ )
4     FORMAT(2X,' 4  ENTER ROUTE NO:          => ',\ )
5     FORMAT(2X,' 5  ENTER CROSSING INFO      => ',\ )
6     FORMAT(2X,' 6  ENTER LOCATION INFO     => ',\ )
7     FORMAT(2X,' 7  ENTER LOG-MILE          => ',\ )
8     FORMAT(2X,' 8  TYPE-MAIN SPANS          => ',\ )

```

```

9      FORMAT(2X,' 9 TYPE-APPROACH SPANS      => ',\)\
10     FORMAT(2X,'10 ENTER NO. MAIN SPANS      => ',\)\
11     FORMAT(2X,'11 ENTER NO. SPANS-APPR.      => ',\)\
12     FORMAT(2X,'12 ENTER SPAN LENGTHS        => ',\)\
13     FORMAT(2X,'13 NO. LANES ON STR.         => ',\)\
14     FORMAT(2X,'14 NO. LANES UNDER STR.      => ',\)\
15     FORMAT(2X,'15 ENTER SKEW (DEGREE)        => ',\)\
16     FORMAT(2X,'16 STRUCTURE LENGTH          => ',\)\
17     FORMAT(2X,'17 TOTAL HORIZ. CL. OV.       => ',\)\
18     FORMAT(2X,'18 TOTAL HORIZ. CL. UN.       => ',\)\
19     FORMAT(2X,'19 CURB\WALK WIDTH RT.        => ',\)\
20     FORMAT(2X,'20 CURB\WALK WIDTH LT.        => ',\)\
21     FORMAT(2X,'21 DECK WIDTH CURB-CURB       => ',\)\
22     FORMAT(2X,'22 DECK WIDTH 0-0 COPING      => ',\)\
23     FORMAT(2X,'23 MIN. VERT. CL. OVER DECK   => ',\)\
24     FORMAT(2X,'24 MIN. VERT. CL.UNDER STR.   => ',\)\
25     FORMAT(2X,'25 MIN.HORIZ.CL.UN.STR. RT.  => ',\)\
26     FORMAT(2X,'26 MIN.HORIZ.CL.UN.STR. LT.  => ',\)\
27     FORMAT(2X,'27 APPROACH RDWY. WIDTH      => ',\)\
28     FORMAT(2X,'28 SAFETY - BR.RAIL 0/1      => ',\)\
29     FORMAT(2X,'29 RAIL TRANSITION 0/1       => ',\)\
30     FORMAT(2X,'30 APPROACH RAIL 0/1         => ',\)\
31     FORMAT(2X,'31 TERMINAL END 0/1          => ',\)\
32     FORMAT(2X,'32 CITY/TOWN LIMIT           => ',\)\
33     FORMAT(2X,'33 NAME OF INSPECTOR         => ',\)\
34     FORMAT(2X,'34 ENTER DATE (MM/DD/YY)     => ',\)\

```

```

RETURN
END

```

```

SUBROUTINE ELDEF(II)

```

C
C
C

```

DEFICIENCIES APPRAISAL

```

```

CHARACTER IPRT(90)*2
COMMON/PRT/IPRT

```

```

IF (II.LE.1000) WRITE(*,1000)
IF (II.EQ.1001) WRITE(*,1001) IPRT(81)
IF (II.EQ.1002) WRITE(*,1002) IPRT(82)
IF (II.EQ.1003) WRITE(*,1003) IPRT(83)
IF (II.EQ.1004) WRITE(*,1004) IPRT(84)
IF (II.EQ.1005) WRITE(*,1005) IPRT(85)
IF (II.EQ.1006) WRITE(*,1006) IPRT(86)

```

```

1000  FORMAT(//,7X,10HDEFICIENCY,10X,10H PREVIOUS ,12X,9H PRESENT
&      /,7X,10HITEM 67-72,10X,10H RATING ,12X,8H RATING
&      /,7X,10H -----,10X,10H ----- ,12X,8H-----,/)

1001  FORMAT(2X,'1. STRUCTURAL CONDITION',5X,[' ',A1,']'18X,'=>',\)\
1002  FORMAT(2X,'2. DECK GEOMETRY',5X,[' ',A1,']'18X,'=>',\)\
1003  FORMAT(2X,'3. UNDER CLEARANCE',5X,[' ',A1,']'18X,'=>',\)\
1004  FORMAT(2X,'4. SAFE LOAD CAPACITY',5X,[' ',A1,']'18X,'=>',\)\
1005  FORMAT(2X,'5. WATERWAY ADEQUACY',5X,[' ',A1,']'18X,'=>',\)\
1006  FORMAT(2X,'6. APPROACH ALIGNMENT',5X,[' ',A1,']'18X,'=>',\)\
RETURN
END

```


SUBROUTINE SHOWDF

DISPLAY DEFICIENCY APPRAISAL ITEMS

```

CHARACTER IPRT(90)*2
CHARACTER RATE(20)*2, REM(90)*30
COMMON /NRT/RATE
COMMON /MSG/REM
COMMON /PRT/IPRT
WRITE(*,100)
WRITE(*,101) IPRT(81),RATE(1),REM(81)
WRITE(*,102) IPRT(82),RATE(2),REM(82)
WRITE(*,103) IPRT(83),RATE(3),REM(83)
WRITE(*,104) IPRT(84),RATE(4),REM(84)
WRITE(*,105) IPRT(85),RATE(5),REM(85)
WRITE(*,106) IPRT(86),RATE(6),REM(86)
100  FORMAT(7X,13H DEFICIENCIES,9X,5HOLD ,3X,5HNEW
& /,7X,13H APPRAISAL ,9X,5HDATA ,3X,5HDATA ,10X,8H REMARKS
& /,7X,13H -----,9X,5H---- ,3X,5H---- ,10X,8H ----- ,/)
101  FORMAT(2X,'1. STRUCTURAL CONDITION ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30)
102  FORMAT(2X,'2. DECK GEOMETRY ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30)
103  FORMAT(2X,'3. UNDER CLEARANCE ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30)
104  FORMAT(2X,'4. LOAD CAPACITY ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30)
105  FORMAT(2X,'5. WATERWAY ADEQUACY ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30)
106  FORMAT(2X,'6. APPROACH ALIGNMENT ',2X,['',A1,'']'5X,['',A1,'']
&,3X,'> ',A30,/)

RETURN
END

```

SUBROUTINE PROPOSE(I)

IMPROVEMENT PROPOSAL

```

IF (I.EQ.1 ) WRITE(*,101)
IF (I.EQ.2 ) WRITE(*,102)
IF (I.EQ.3 ) WRITE(*,103)
IF (I.EQ.4 ) WRITE(*,104)
IF (I.EQ.5 ) WRITE(*,105)
IF (I.EQ.6 ) WRITE(*,106)
IF (I.EQ.7 ) WRITE(*,107)
IF (I.EQ.8 ) WRITE(*,108)
IF (I.EQ.9 ) WRITE(*,109)
IF (I.EQ.10) WRITE(*,110)
IF (I.EQ.11) WRITE(*,111)
IF (I.EQ.12) WRITE(*,112)
IF (I.EQ.13) WRITE(*,113)
IF (I.EQ.14) WRITE(*,114)
IF (I.EQ.15) WRITE(*,115)
IF (I.EQ.16) WRITE(*,116)

```

```

IF (I.EQ.17) WRITE(*,117)
IF (I.EQ.18) WRITE(*,118)
IF (I.EQ.19) WRITE(*,119)
IF (I.EQ.20) WRITE(*,120)
IF (I.EQ.21) WRITE(*,121)
IF (I.EQ.22) WRITE(*,122)
IF (I.EQ.23) WRITE(*,123)
IF (I.EQ.24) WRITE(*,124)
IF (I.EQ.25) WRITE(*,125)
IF (I.EQ.26) WRITE(*,126)
IF (I.EQ.27) WRITE(*,127)
IF (I.EQ.28) WRITE(*,128)
IF (I.EQ.29) WRITE(*,129)
IF (I.EQ.30) WRITE(*,130)
IF (I.EQ.31) WRITE(*,131)
IF (I.EQ.32) WRITE(*,132)
IF (I.EQ.33) WRITE(*,133)
IF (I.EQ.34) WRITE(*,134)
IF (I.EQ.35) WRITE(*,135)
IF (I.EQ.36) WRITE(*,136)
IF (I.EQ.37) WRITE(*,137)
IF (I.EQ.38) WRITE(*,138)
IF (I.EQ.39) WRITE(*,139)
IF (I.EQ.40) WRITE(*,140)
IF (I.EQ.41) WRITE(*,141)
IF (I.EQ.42) WRITE(*,142)
IF (I.EQ.43) WRITE(*,143)
IF (I.EQ.44) WRITE(*,144)
IF (I.EQ.45) WRITE(*,145)
IF (I.EQ.46) WRITE(*,146)
IF (I.EQ.47) WRITE(*,147)
IF (I.EQ.48) WRITE(*,148)
IF (I.EQ.49) WRITE(*,149)
101  FORMAT(8X' REPAVE SURFACE
102  FORMAT(8X' REPAIR OR REPLACE DECK
103  FORMAT(8X' REPAIR CURBS
104  FORMAT(8X' REPAIR MEDIAN
105  FORMAT(8X' REPAIR SIDEWALKS
106  FORMAT(8X' REPAIR PARAPET
107  FORMAT(8X' REPAIR RAILING
108  FORMAT(8X' REPAINTING OF DECK
109  FORMAT(8X' CLEAN AND REPAIR DRAINS
110  FORMAT(8X' CHECK LIGHTING FIXTURES
111  FORMAT(8X' CHECK UTILITIES
112  FORMAT(8X' CHECK FOR LEAKAGE
113  FORMAT(8X' REPAIR EXPANSION JOINTS
114  FORMAT(8X' REPAIR BEARING DEVICES
115  FORMAT(8X' REPLACE OR REPAIR STRINGERS
116  FORMAT(8X' REPLACE OR REPAIR MAIN SUPPORTING MEMBERS
117  FORMAT(8X' REPAIR OR REPLACE FLOOR BEAMS
118  FORMAT(8X' REPAIR OR REPLACE TRUSSES
119  FORMAT(8X' REPAINT MAIN STRUCTURE
120  FORMAT(8X' REPAIR MOVABLE MACHINERY
121  FORMAT(8X' REPLACE RIVETS OR BOLTS
122  FORMAT(8X' REWELDING OF MEMBERS
123  FORMAT(8X' CORROSION PROTECTION OF SUPERSTRUCTURE
124  FORMAT(8X' REPLACE TIMBER MEMBERS

```

```

125  FORMAT(8X' REPAIR CONCRETE MEMBERS DUE TO CRACKING          ')
126  FORMAT(8X' REPLACE OR REPAIR COLLISION DAMAGED MEMBERS    ')
127  FORMAT(8X' CHECK FOR SEVERE DEFLECTION                     ')
128  FORMAT(8X' REALIGNMENT OF MEMBERS                          ')
129  FORMAT(8X' CHECK OF VIBRATION PROBLEMS                     ')
130  FORMAT(8X' REPAIR BRIDGE SEATS                             ')
131  FORMAT(8X' REPAIR ABUTMENT WINGS                           ')
132  FORMAT(8X' REPAIR ABUTMENT BACKWALL                       ')
133  FORMAT(8X' REPAIR ABUTMENT FOOTING                         ')
134  FORMAT(8X' REPLACE ABUTMENT PILES                          ')
135  FORMAT(8X' PROTECT ABUTMENT EROSION                       ')
136  FORMAT(8X' CHECK ABUTMENT SETTLEMENT                      ')
137  FORMAT(8X' REPAIR PIER CAPS                                ')
138  FORMAT(8X' REPAIR PIER COLUMN                              ')
139  FORMAT(8X' REPAIR PIER FOOTING                             ')
140  FORMAT(8X' REPAIR PIER PILES                              ')
141  FORMAT(8X' PROTECT BRIDGE SCOUR                           ')
142  FORMAT(8X' CHECK PIER SETTLEMENT                          ')
143  FORMAT(8X' CHECK AND REPAIR PILE BENTS                     ')
144  FORMAT(8X' REPAIR CONCRETE CRACKING ON SUBSTRUCTURE       ')
145  FORMAT(8X' REPAIR STEEL CORROSION ON SUBSTRUCTURE         ')
146  FORMAT(8X' REPAIR TIMBER DECAY ON SUBSTRUCTURE            ')
147  FORMAT(8X' CLEAN DEBRIS ON SEATS                           ')
148  FORMAT(8X' REPAINT SUBSTRUCTURE                           ')
149  FORMAT(8X' REPAIR COLLISION DAMAGE ON SUBSTRUCTURE        ')

```

```

RETURN
END

```

```

SUBROUTINE INTRO(TYPE)

```

```

INTRODUCTION

```

```

CHARACTER TYPE*4
WRITE(*,100)
IF (TYPE.EQ.'DECK') THEN
    WRITE(*,200)
ELSE IF(TYPE.EQ.'SUPS')THEN
    WRITE(*,400)
ELSE IF(TYPE.EQ.'SUBS')THEN
    WRITE(*,600)
ELSE IF(TYPE.EQ.'CHNL')THEN
    WRITE(*,700)
ELSE IF(TYPE.EQ.'CULV')THEN
    WRITE(*,800)
    WRITE(*,801)
ELSE IF(TYPE.EQ.'APPR')THEN
    WRITE(*,820)
ELSE IF(TYPE.EQ.'LOAD')THEN
    WRITE(*,840)
ELSE IF(TYPE.EQ.'DEFY')THEN
    WRITE(*,860)
ENDIF

```

```

100  FORMAT (15X  ' *****',
&    /,15X,  ' *          C O N D I T I O N          * ',
&    /,15X,  ' *          I N S P E C T I O N          * ',

```

```

&      /,15X, ' *****
&      //,15X, ' TYPE      N = TO ENTER NOTES OR REMARKS
&      /,15X, '           U = TO UNDO LAST ENTRY
&      /,15X, '           - = FOR NOT APPLICABLE ENTRY
&      /,15X, '           H = FOR HELP
&      /,15X, '           D = DELETE AN ENTRY
&      /,15X, '           R = REDO FROM BEGINNING
&      /,15X, '           0 - 9 = TO ENTER RATING
&      //,15X, '           (hit CTRL-BREAK to abort)
&      /,15X, '           (you may use capital or small letters) '//' )

200  FORMAT (15X, ' THE DECK ' //)
400  FORMAT (15X, ' THE SUPERSTRUCTURE ' //)
600  FORMAT (15X, ' THE SUBSTRUCTURE ' //)
700  FORMAT (15X, ' CHANNEL PROTECTION ' //)
800  FORMAT (15X, ' CULVERT & RETAINING WALLS ' //)
801  FORMAT (15X, ' (rating given only for underfill structures) ')
820  FORMAT (15X, ' APPROACH ALIGNMENT ' //)
840  FORMAT (15X, ' POSTED LOADING ' //)
860  FORMAT (///,15X, ' DEFICIENCIES ',
&      /,15X, ' APPRAISAL ' //)

RETURN
END

SUBROUTINE ELTYPE(TYPE,IFMT)

C
C  SELECT ELEMENT TYPE
C
CHARACTER TYPE*4

      IF(TYPE.EQ.'DECK') THEN
        CALL MDECK(IFMT)
      ELSE IF(TYPE.EQ.'SUPS') THEN
        CALL MSUP(IFMT)
      ELSE IF(TYPE.EQ.'SUBS') THEN
        CALL MSUB(IFMT)
      ELSE IF(TYPE.EQ.'CHNL') THEN
        CALL MCHNL(IFMT)
      ELSE IF(TYPE.EQ.'CULV') THEN
        CALL MCULV(IFMT)
      ELSE IF(TYPE.EQ.'APPR') THEN
        CALL MAPPR(IFMT)
      ELSE IF(TYPE.EQ.'LOAD') THEN
        CALL MLOAD(IFMT)
      ENDIF
      RETURN
      END

SUBROUTINE REDRAW(TYPE)

C
C  DISPLAY INFORMATION
C
CHARACTER TYPE*4

      IF (TYPE.EQ.'DECK') THEN
        CALL SHOWDK

```

```

ELSE IF(TYPE.EQ.'SUPS')THEN
  CALL SHOWSP
ELSE IF(TYPE.EQ.'SUBS')THEN
  CALL SHOWSB
ELSE IF(TYPE.EQ.'CHNL')THEN
  CALL SHOWCH
ELSE IF(TYPE.EQ.'CULV')THEN
  CALL SHOWCV
ELSE IF(TYPE.EQ.'APPR')THEN
  CALL SHOWAP
ELSE IF(TYPE.EQ.'LOAD')THEN
  CALL SHOWLD
ENDIF
RETURN
END

```

```

SUBROUTINE BORDER

```

C
C
C

```

DRAW LINES

```

```

CHARACTER*1 STAR(75)
DATA STAR /75*'*/
WRITE(*,*)(STAR(I),I=1,75)
RETURN
END

```


COVER DESIGN BY ALDO GIORGINI