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BRIDGE CONSTRUCTION EXPERT SYSTEM

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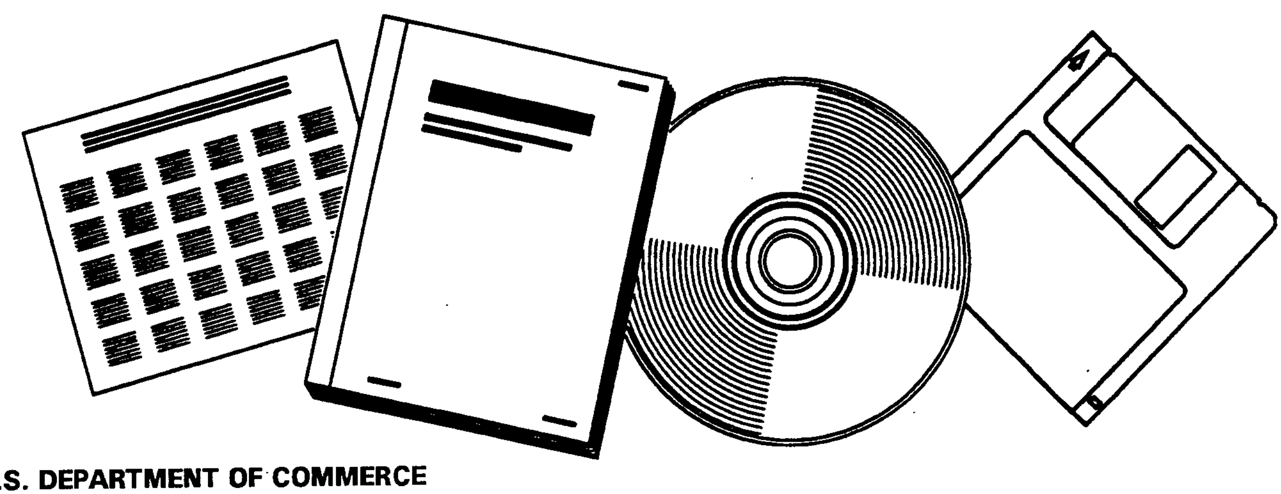

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Final Report

BRIDGE CONSTRUCTION EXPERT SYSTEM

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Kansas State University
Manhattan, Kansas

September 1996

K-TRAN

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:
KANSAS DEPARTMENT OF TRANSPORTATION
THE KANSAS STATE UNIVERSITY
THE UNIVERSITY OF KANSAS

BRIDGE CONSTRUCTION EXPERT SYSTEM

by

Amy Moran Sramek
Hani G. Melhem

Final Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION

K-TRAN PROJECT KSU-92-4

September 1996

Department of Civil Engineering
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PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program. The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

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DISCLAIMER

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16. Abstract

The major goal of the Bridge Construction Expert System (BCX) is to assist young bridge engineers and inspectors in determining the extent of damage due to construction errors and specifying the necessary repair solution. BCX was created to provide a unified repair procedure by gathering domain expertise from designers, construction engineers, inspectors and contractors. The goal was to create a system that would provide the most suitable repair in a timely manner and provide training to prevent future errors from occurring. The scope of the system was limited to pier footings with the exception of drilled shafts*. The development strategy was designed to deliver a system that addresses the real needs and that will function as a tool for training and determining solutions to construction errors.

Knowledge for the system was acquired through case histories, expert interviews and current documentation in the area. The use of case histories was found to be unsuccessful because of the lack of documentation of simple errors. The majority of the knowledge used for the system was acquired through interviews with the experts. The system was designed in three modules with submodules to facilitate future expansion.

Validation and verification of the system was conducted by allowing the expert panel members to run test cases. Eighty percent of the 90 test cases produced correct repair recommendations. The remaining 20 percent produced correct recommendations after a logic error was corrected.

The completion of this project has expanded the expert system development by providing better allocation of resources, more consistent quality solutions, and improved personnel productivity and performance which leads to improved efficiency and reliability at reduced cost. The development goal has been met by creating a system that will provide the most suitable repair solution and serve as an expeditious training aid to help prevent future errors from occurring.

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ABSTRACT

Errors arising during the construction of bridges may have a catastrophic effect on the performance of a completed highway bridge if they are not properly assessed and corrected. The major goal of the Bridge Construction Expert System (BCX) is to assist young bridge construction engineers and inspectors in determining the extent of damage due to construction errors and specifying the necessary repair solution. BCX was created to provide a unified repair procedure for the Kansas Department of Transportation (KDOT) by gathering domain expertise from designers, construction engineers, inspectors, and contractors. The development goal was to create a system that would provide not only the most suitable repair solution in a timely manner, but also a system that would provide training to prevent future errors from occurring. The scope of the system was limited to pier footings with the exception of drilled shafts. A successful system was developed by creating panels of domain experts and users and interacting with these groups beginning early in the project and continuing throughout the development of the system. The development strategy has been deliberately designed to deliver a system that addresses the real needs of KDOT, and that will become a functional tool for training and determining solutions to construction errors.

Knowledge for the system was acquired through case histories, expert interviews, and current documentation in the area. The use of case histories for the development was found to be unsuccessful because of the lack of documentation of simple errors. The majority of the knowledge used for the development was acquired through interviews with the experts. In order to ease future expansion, the system was designed in three modules with submodules that cover specific areas within the module topic. This format allows the program to be easily

maintained and modified as future development occurs or future cases become available. Validation and verification of the system was conducted by allowing the panel members to run test cases on the system. Ninety cases were tested. Of those cases, 80 percent produced correct repair recommendations. The remaining 20 percent were incorrect because of a simple logic error that was later corrected.

The development of this project has successfully continued expert system development for the Kansas Department of Transportation. This system provides better allocation of scarce resources, more consistent quality solutions, and improved personnel productivity and performance which leads to improved efficiency and reliability at reduced cost. In addition, the development goal has been met by creating a system that will provide not only the most suitable repair solution in a timely manner, but also an expeditious training aid which can help to prevent future errors from occurring.

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1.0 Introduction

Errors arising during the construction stage may have a catastrophic effect on the performance of a completed highway bridge. For example, the mislocation of a spread or pile footing could result in the cascading effect of mislocating the column and then mislocating a stiffener in the girder superstructure. Thus, it is essential to correctly determine the significance of each construction error and take appropriate corrective action. More commonly, construction errors can cause delays in the construction process. Mislocated pier footings can stop construction while bridge designers determine a repair solution for the error. Unfortunately, it can be difficult to properly assess error criticality and promptly determine corrective action due to the large network of construction and design specifications involved and the importance of understanding the role that the flawed element will play in the final structure. All the information needed to support a good decision may not be available at the right time and in the right place to solve the problem in the restricted time necessary to keep the job on schedule. This problem is an excellent one to address with a knowledge-based expert system approach.

Unlike conventional programs which only make numerical computations, knowledge-based expert systems make intelligent decisions within their area of specialization. This technology was first developed by computer scientists working in artificial intelligence using special-purpose languages and large computers. Now many expert systems can be created and run using relatively inexpensive software on personal computers.

1.1 Purpose

The objective of this research was to develop an expert system that would include a system to find solutions to pier footing construction errors of bridges and to train young engineers and inspectors of possible pier footing construction errors as a means to prevent future errors. This document charts an expeditious and appropriate transfer of knowledge-based expert system technology to the Kansas Department of Transportation (KDOT) through the development of an application targeted at the resolution of errors arising during the construction of highway bridges.

1.2 Overview of Development Process

To meet the objectives of this project, a specific development methodology was defined at the beginning of the project which consisted of: (1) project identification and selection, (2) feasibility analysis, (3) formation of panels, (4) definition of goals, (5) knowledge acquisition, (6) knowledge engineering, (7) validation and verification, and (8) project evaluation and documentation. This sequence is shown in Figure 1. Each task is briefly discussed below with reference made to those sections of this report discussing a particular development task in more detail.

1.2.1 Project Identification and Selection

The project identification and selection began with generating a list of candidate applications for expert system development for the Kansas Department of Transportation. One of these applications was then selected based on the organizational commitment, evaluation of payoff, urgency and benefits, and goals and expectations. This phase of the development is discussed in depth in Section 3.1.

1.2.2 Feasibility Analysis

The feasibility analysis evaluated the selected application to determine the likelihood of success. The main features analyzed were the technical suitability of the problem and availability of expertise in the problem area. The feasibility analysis is covered in greater detail in Section 3.2.

1.2.3 Formation of Panels

With KDOT's cooperation, two panels, the Panel of Experts (PoE) and the Panel of Users (PoU), were assembled. Each panel consisted of seven individuals, including design engineers, field engineers, consulting engineers, and contractors. The formation of these panels is covered in greater detail in Section 3.3

1.2.4 Definition of Goals

A survey was performed on the knowledge available, the techniques presently used, current construction practice(including KDOT bridge manual), and the general literature coverage of the problem domain. The needs of the bridge community in general, and KDOT in particular, were identified prior to the development of the knowledge base. The specific goals of this project are described in Section 3.4.

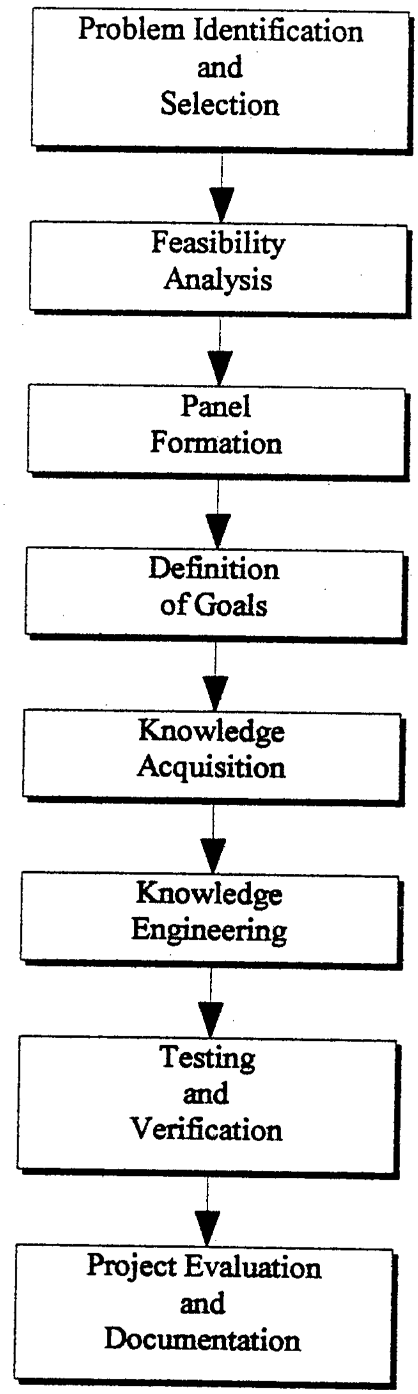

Figure 1. BCX Development Methodology

1.2.5 Knowledge Acquisition

Knowledge acquisition entails extracting domain knowledge from literature, documentation of current procedures, and interviews of the experts in the field. Knowledge acquisition for this expert system was completed using (1) questionnaires to KDOT bridge engineers, construction personnel, field inspectors, and contractors; (2) interviews with KDOT bridge engineers, construction personnel, field inspectors, and contractors; (3) historical records such as case studies, bridge databases, and inspection reports; and (4) simulated results for hypothetical situations. The collection of information and cases was used for the knowledge engineering development phase described below. Additional information on the knowledge acquisition phase can be found in Section 3.5.

1.2.6 Knowledge Engineering

Knowledge engineering entailed structuring the system knowledge-bases and creating the rules of the expert system. It also entailed developing the user interface (input/output screens, pull-down menus, inquiry boxes and hyper regions, and textual descriptions of the problem.) Further detail on these phases can be found in Section 3.6.

1.2.7 Validation and Verification

The validation and verification of the system was completed by holding workshops attended by the research team, the panel of experts and the panel of users. During these workshops, the system was demonstrated and its performance was discussed and evaluated based on appropriate case studies. Feedback and comments were incorporated in the revised versions of the system when appropriate. The testing methodology is described in Section 3.7 and the results are described in Section 4.0.

1.2.8 Project Evaluation and Documentation

An assessment was made of the effectiveness and efficiency of the system development and the extent to which the project and expert system met the initial goals and expectations. In addition, comparisons were made to the existing expert system currently in use at KDOT. The project evaluation and documentation are discussed in Section 3.8.

2.0 Background

2.1 Knowledge-Based Expert Systems

Knowledge-based expert systems have become a very useful tool for many engineering applications. Expert systems are computer programs that use an expert's knowledge to solve problems within their area of expertise. They model the problem solving abilities of the expert. This section discusses the personnel involved in the development, the structure, the types of knowledge, the knowledge representation techniques, the inference strategies, the advantages and the disadvantages of an expert system.

2.1.1 Personnel

An expert system is developed with the cooperation of the domain experts, the expected end users, and the knowledge engineer.

Domain Experts

Experts are people that are trusted and respected. They are considered experts because of their personal experience, reputation and standing. In short, experts are experts because of what they are able to do with their acquired knowledge. Experts can be characterized by the following features (Hart 1986):

Effective - An expert uses his knowledge to solve problems with an acceptable rate of success.

Efficient - An expert must not only solve problems, but must also be able to deduce more probable solutions and quickly determine the most relevant information.

Aware of limitations - An expert is aware of the scope of his knowledge.

An expert is consulted as a provider of information, as a problem-solver and as an explainer. Consultations with experts allow non-experts to learn as well as build confidence.

The experts are a vital part of the development of an expert system, therefore, the enthusiasm of the experts for the project may be the most important key to its success. Two simple points can be made to encourage the experts. Firstly, the expert system when developed will only handle the straightforward problems that probably represent 90% of their work, but work that is rather boring. Thus allowing them time for the really difficult and interesting problems. Secondly, impending retirement with a natural pride of trying to preserve a lifetime's experience for others, can be another strong motivator (Allwood 1989).

Knowledge Engineer

The knowledge engineer is the person who acquires the domain knowledge, and builds and tests the expert system. The knowledge engineer must interact with both the experts and the end-users. Therefore, it is very important that the knowledge engineer has the right inter-personal skills (Feigenbaum & McCorduck 1984; Welbank 1983). Some of these are described below (Hart 1986):

Good communication skills - effective use of the spoken and written word, diagrammatic representation, and interpretation of body language.

Intelligence - The knowledge engineer is continually learning and must be able to learn about a new knowledge domain, and understand enough of the terminology and principles to be able to discuss it fully with an acknowledged expert.

Tact and diplomacy - The success of the project will depend on the cooperation of a number of important experts. An expert who has been alienated by thoughtless or tactless treatment will tend to lose interest. Any suggestion that a program can replace or outperform the expert can be disastrous. So is an intimation that the expert is failing to provide the right information in an appropriate way.

Empathy and patience - The knowledge engineer and expert must work together as a team, each respecting the other. This means that the knowledge engineer must appreciate the problems faced by the expert. He needs to encourage without being patronizing, to argue without appearing self-opinionated, and ask for clarification without appearing critical. If he realizes the reasons for the expert's hesitancy or apparent incoherence then he will be able to exercise sufficient patience.

Persistence - Results may come slowly. Ultimately, there must be no gaps or inconsistencies, but during development there may be many. In order to resolve problems the knowledge engineer must persist; must retain enthusiasm and belief in the project. Despite setbacks, the knowledge engineer must persist in the conviction that success will come.

Logicality - The inference mechanism of the expert system must be consistent and logical. During knowledge elicitation, especially the early stages, the expert's explanations may seem confused or fragmented. The elicitor needs to be able to argue reasonable, recognizing valid statements and providing meaningful counter examples for possible errors. The completeness and consistency of the emerging model must also be assessed. All of this requires a level of clear thought and logicality.

Versatility and inventiveness - Using judgement to select methods which seem appropriate, and abandoning those which are not effective. The knowledge engineer may have to discard early results or models, and if necessary invent representations which suit the expert and the domain. This requires an informed, versatile approach to the project, together with an ability and willingness to try new ideas.

Self confidence - The combination of these qualities and skills must be matched by self confidence. A shy or immature person, however technically able, would not be able to control a project. The development of an expert system is a challenge, and the knowledge engineer must have enough self confidence to sustain enthusiasm for the project. At the same time this confidence must not result in bombastic or patronizing behavior.

Domain knowledge - The knowledge engineer has to talk to the expert using the expert's terminology. It would be advantageous, therefore, for the knowledge engineer to have some background knowledge of the domain, for example, the types of problems encountered, the terminology, accepted methods and tools.

Programming knowledge - The knowledge base and inference mechanisms used by the expert will be implemented in a program. It is advisable, but not essential, that the knowledge engineer understands programming and the various forms of knowledge representation available. However, during knowledge elicitation an intelligent and versatile approach is most important, and some deficiencies in computer science experience can be tolerated.

It is unlikely that a knowledge engineer would have all these qualities, this list is included to give an idea of the optimal person's talents and the ways in which they are likely to be needed. However, it is certain that the selection of the knowledge engineer will have a crucial effect on the success of a project.

End-users

The end-users are the individuals who will eventually be working with the system. Final acceptance of the system will depend to a large degree on how well the system meets the needs of the end-users (Durkin 1994). The end-users should be responsible for specifying how the expert system should be accessed, how the information is entered, how the system provides explanations, what additional utilities should be used for support (i.e., databases, spreadsheets), and how the system's interface is designed. If the end-users are not involved in the project from the beginning, no matter how powerful the expert system, the project is likely to fail the ultimate test: *Will it be used?* (Durkin 1994).

2.1.2 Structure

A human expert is someone that has specialized knowledge in a particular area, known as **domain knowledge**. This domain knowledge is stored in the expert's long-term memory. Human experts are commonly used as advisors. When advising, the expert obtains the facts about the problem, and stores them in short-term memory. Using the short-term memory facts and the long-term memory knowledge, the expert reasons about the problem, infers new problem information and eventually arrives at a conclusion. This problem solving approach is shown in Figure 2. Expert systems are computer programs that solve problems using a process that is very similar to the methods used by a human expert. The expert system problem solving approach is shown in Figure 3.

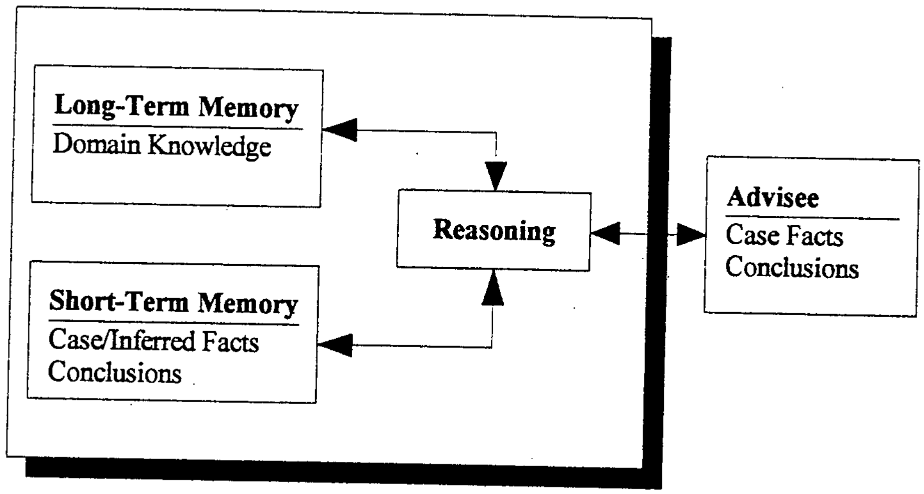

Figure 2. Human Expert Problem Solving (After Durkin 1994).

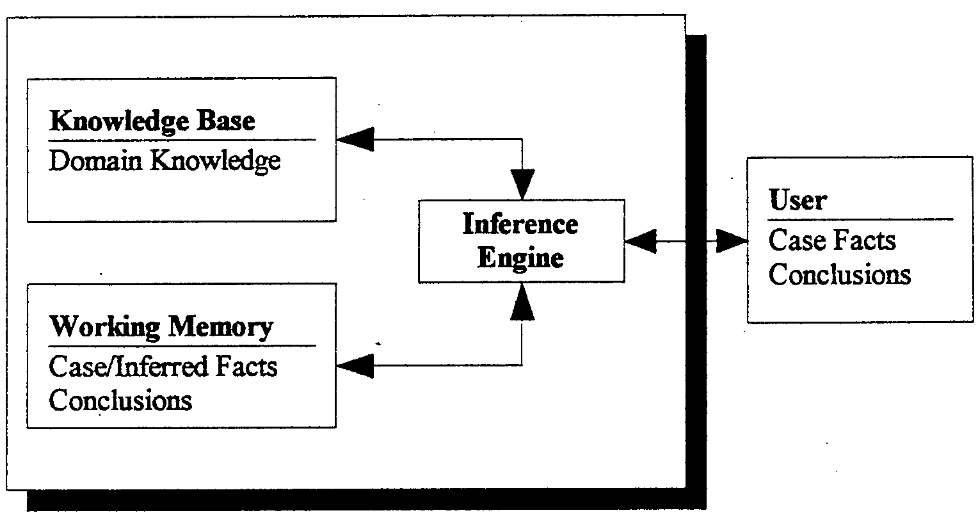

Figure 3. Expert System Problem Solving (After Durkin 1994).

The long-term memory of an expert system contains the domain knowledge and is known as the **knowledge base**. The short-term memory of an expert system contains the facts about the problem that are entered during a consultation and is stored in the working memory of the computer. The **inference engine** is the processor in an expert system that matches the facts contained in the working memory with the domain knowledge contained in the knowledge base, to draw conclusions about the problem. The final element of the expert system is the interface between the expert system and the end users referred to as the **user interface**. The construction of an expert system is simplified by using a commercial expert system shell. The **expert system shell** is a building tool that provides programming, knowledge representation, inference capabilities and user interfaces.

2.1.3 Types of Knowledge

The knowledge obtained from the experts and the literature is contained within the knowledge base and can be classified an several ways. **Procedural knowledge** describes how a problem is solved and provides direction on how to do something. Rules, strategies, agendas and procedures, are the typical type of procedural knowledge used in expert systems. **Declarative knowledge** describes what is known about a problem and includes simple statements that are asserted to be either true or false. **Meta-knowledge** describes knowledge about knowledge and is used to pick other knowledge that is best suited for solving a problem. **Heuristic knowledge** describes a rule-of-thumb that guides the reasoning process. It represents the knowledge compiled by an expert through the experience of solving past problems. **Structural knowledge** describes an expert's overall mental model of concepts, subconcepts, and objects. Table 1 shows these different types of knowledge.

Types of Knowledge

Procedural Knowledge	Rules Strategies Agendas Procedures
Declarative Knowledge	Concepts Objects Facts
Meta-Knowledge	Knowledge About the Other Types of Knowledge and How to Use Them
Heuristic Knowledge	Rules of Thumb
Structural Knowledge	Rule sets Concept Relationships Concept to Object Relationships

Table 1. Different types of knowledge (Durkin 1994).

2.1.4 Knowledge Representation Techniques

There are several techniques used to represent this knowledge within an expert system. An **Object-Attribute-Value Triplet** is a fact of knowledge used to define a particular property value of some object. For example, the statement "the pile's mislocation is 10 inches" assigns a value of "10 inches" to the pile's mislocation. Attributes can be single- or multi-valued. **Rules** are a knowledge structure that relates some known information to other information that can be concluded or inferred to be known. The rule is structured as follows: IF a set of propositions (antecedent) is True THEN one or more conclusion (consequent). **Semantic Networks** are a knowledge representation technique that uses a graph made up of nodes and arcs where the nodes represent objects and the arcs the relationships between the objects. For example, a node may be labeled substructure unit and the arc may be labeled IS A or HAS to define the relationship between the connected nodes. **Frames**, an extension of the semantic network, are data structures for representing stereotypical knowledge of some concept or object.

2.1.5 Inference Strategies

The inference engine determines what questions are asked of the user and how to use the information given by the user. In other words, it directs the consultation. Two inference strategies (also known as control strategies) can be used in combination or alone by the inference engine. **Forward-chaining** begins with a set of known facts, derives new facts using rules whose premises match the known facts, and continues this process until a goal state is reached or until no further rules have premises that match the known or derived facts. **Backward-chaining** attempts to prove a hypothesis by gathering supporting information. A **goal agenda** is a series of goals to pursue in a prescribed sequence and directs the searching of the inference engine. An indirect combination of forward and backward chaining can be accomplished by using demon rules. A **Demon rule** is a rule that fires whenever its premises match the contents of the working memory.

2.1.6 Advantages

The main advantages of expert systems include: availability, consistency, comprehensiveness, and non-expert training. It generally takes over five years for someone to acquire expertise in a particular area. Expertise is gained from dealing with different cases, and learning patterns and principles which rely on heuristics or rules of thumb. These rules of thumb are seldom documented, thus non-experts must rely on the advice from experts. If the expert's knowledge is encoded into an expert system the availability of that expert expands. In contrast to the human expert, the expert system will not take holidays, become ill, or retire. The knowledge will remain available for training non-experts. In addition, an expert system will be consistently correct, provided it has been formulated correctly. Expert systems to do not have "off" days because of stress or illness. Once an expert system has been proven correct, it will remain correct. Not only will an expert system allow users to easily access consistent expert advice, it will also allow the user to receive an opinion formulated from more than one expert. It is often difficult to get a group of experts to discuss a case and reach a consensus opinion, however, expert systems are developed by using a group of experts. Therefore, the advice from an expert system is the comprehensive advice from a group of experts. The acceptability of expert systems by engineers in an office will hinge on their perception of its value, but there is the advantage that consulting an expert system in the privacy of an office is far less embarrassing than facing a formidable expert. There is also a clear indication already that frequent consultation of an expert system is itself a useful sub-conscious learning process which could be of great value to non-experts.

2.1.7 Disadvantages

There can be definite disadvantages to expert systems if exaggerated claims of their power and usefulness are made. There are a number of areas to consider before developing an expert system: choice of domain, acceptability, and limitations. Some problems cannot efficiently be addressed by an expert system because the domain is not suitable. Those would include problems in which experts are not available or do not even exist, problems that take more than a few hours to solve, and problems that concern frequently changing knowledge. Another consideration should be the acceptability of the finished expert system. There exists a resistance to the use of computers among some individuals. They do not feel that a program can be using the same reasoning that a human expert would. Human experts know their limitations. However, expert systems tend to always produce a result and may in turn over-diagnose. Therefore, it is important to stress that an expert system should be used to assist and not replace.

2. 2 Methodologies Used in the Development of Knowledge-Based Expert Systems

The development of knowledge-based expert systems can be separated into six phases: (1) Problem Assessment, (2) Knowledge Acquisition, (3) System Design, (4) Testing and Evaluation, (5) Documentation, and (6) Maintenance (Durkin 1994; Hart 1986; Allwood 1989). This methodology is shown in Figure 4. These development phases are not sequential, in fact, there is considerable overlap. The development of expert system is an iterative process. In order for the completed system to be successful, these phases must be revisited with refinements as the project progresses.

2.2.1 Problem Assessment

The problem assessment phase consists of determining the organizational motivation, forming a list of candidate applications, conducting a feasibility study, and selecting the candidate application for development. The organizational motivation can be classified in two ways: Problem Driven or Solution Driven. If the organization has the desire to solve a specific existing problem with expert system technology, it's motivation can be classified as problem driven. In this case, a list of candidate applications is unnecessary because a specific problem has already been identified. However, if the organization has the desire to explore the expert system technology, it's motivation can be classified as solution driven. In this case, a list of candidate applications must be developed.

The list of candidate applications should be formed by meeting with middle to upper management personnel with the best overview of the problems that need to be solved by the organization. This meeting should examine problems that involve human decision making,

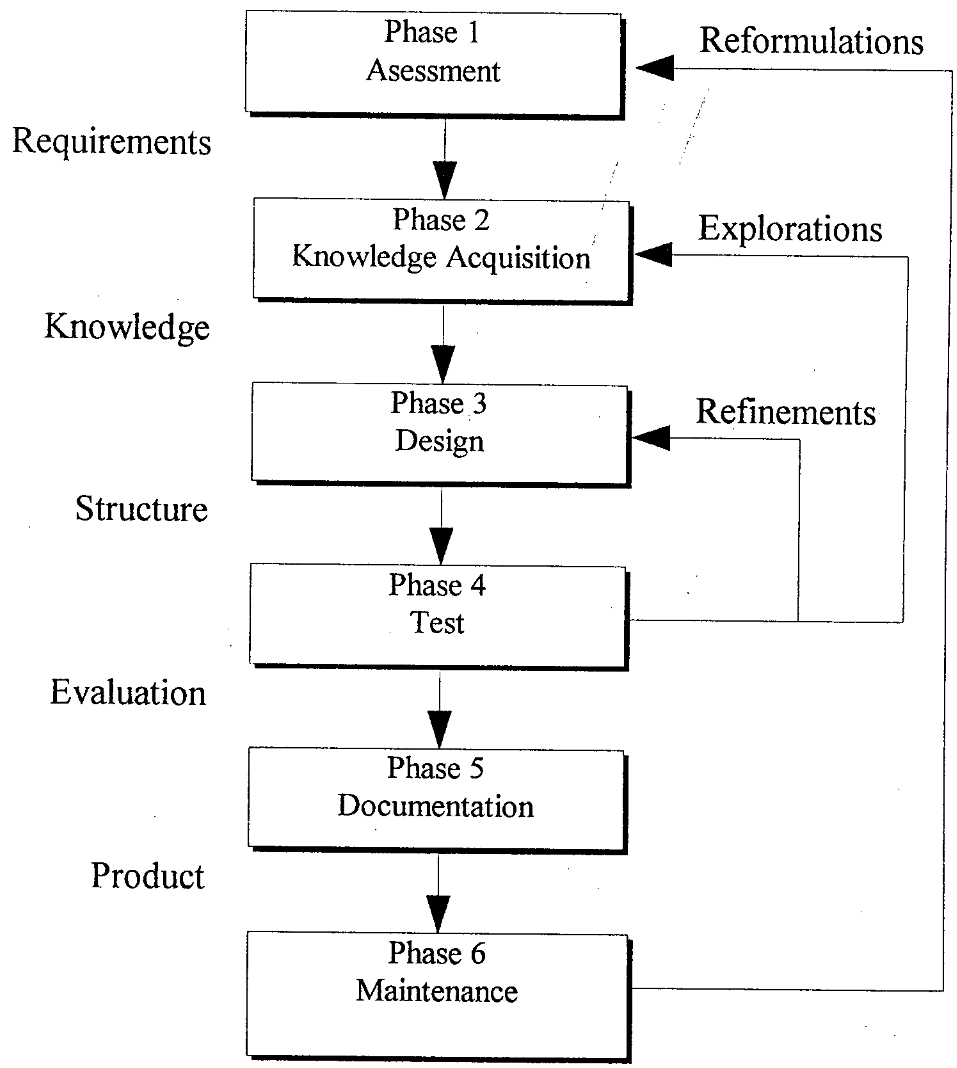

Figure 4. Development Methodology (Durkin 1994)

heuristic knowledge, and judgmental knowledge. Experience has shown (Goodall 1985) that the most successful projects are those with fairly modest objectives, taking about six man-months to develop. The problem should have a clearly defined use and scope. Furthermore, the chosen problem must be sufficiently important to warrant investigation, while being technically feasible. Questions to be asked include (Hayes Roth et al. 1983):

- How important is this problem?
- What would be the advantages of an expert system?
- How common is the problem?
- How important will it be in a few years' time?
- Can the problem be easily defined?
- Would it be practical to use a computer?
- Has anyone tried a similar project elsewhere?
- Who would use the expert system? Why?
- Is there a shell we could use?
- Is there any documentation?
- How do the experts learn their expertise?
- Can we spare an expert's time?
- What resources do we need?
- What might make this project difficult to develop?
- Do the experts disagree?
- How long does it take to become an expert?
- How much can be invested in this project?

- Are there any times when the experts are not available for consultation?
- Is the knowledge complex, needing several inference mechanisms and knowledge representations?
- Will the expert system need updating frequently?
- Can we tolerate imperfect output?
- Will the development of the interface require great effort?

A discussion along these lines will help to identify possible difficulties, to reach agreement on sensible objectives, and to draw up plans for the development of a project having obvious commercial benefits.

Once a list of candidate applications has been formed, the feasibility of these applications should be studied. The main objective of the feasibility study is to determine the likelihood of success. The success of an application can be estimated by examining the project requirements and the project risks as shown in Figure 5. The requirements of the project include the proper resources: computers, software, and funding; and the knowledge source: available experts, case studies, and documentation.

The risks of the project can be classified into three categories: problem, people, and deployment. The risks of the problem are determining whether the application is a viable candidate for expert system development. The characteristics of an appropriate expert system problem are shown in Table 2.

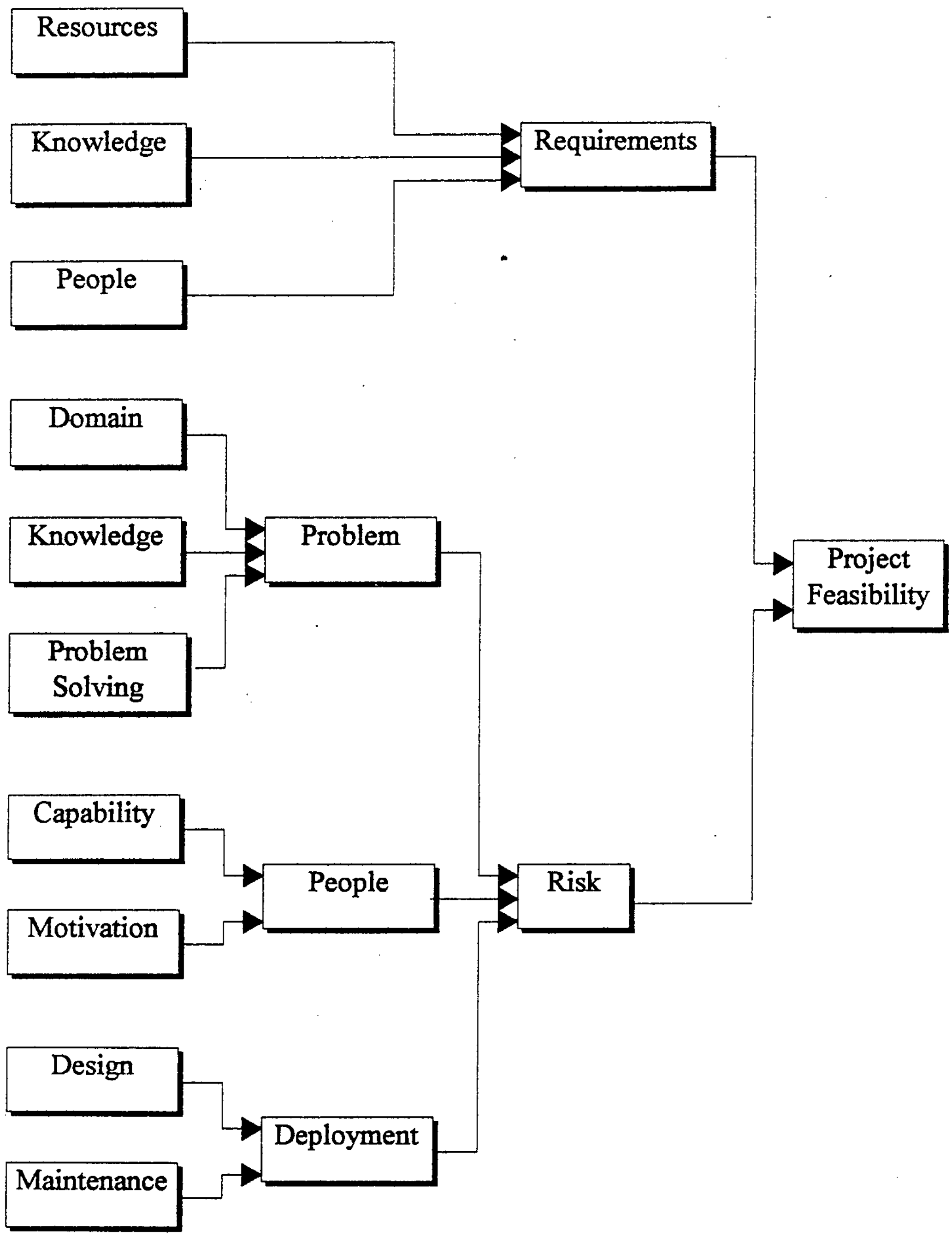

Figure 5. Project Requirements and Risks

Expert knowledge needed	The problem requires expertise to solve, which includes both expert knowledge and expert problem solving skills.
Problem solving steps are definable	The major steps used by the expert when solving the problem can be clearly defined.
Symbolic knowledge used	The type of knowledge used by the expert is symbolic in nature, rather than in the numeric form that is more commonly found in conventional programs.
Heuristics used	The expert uses rules-of-thumb gained from past experiences to guide the problem solving.
Problem is solvable	Expert systems are not intended to address new novel research issues, but rather to solve problems that can currently be solved by human experts.
Successful systems exist	Prior systems in the application area have been successfully built.
Problem is well-focused	The overall scope of the problem is manageable, focused on an issue that is achievable by an expert system approach.
Problem is reasonably complex	The problem is reasonably complex; not too easy where the effort may not be justified, or too difficult where the problem may not be manageable.
Problem is stable	The knowledge and the approach to solving the problem are stable. If changes are likely to occur, then the expert system will need to be modified often.
Uncertain or incomplete knowledge used	The problem requires good judgement to solve because of the uncertainty or incompleteness of the available information.
Non-deterministic	In general, if the problem is deterministic in nature, then a conventional programming approach is usually the better choice.
Solution more of a recommendation	The problem does not require an exact answer - rather, an educated recommendation.

Table 2. Expert system problem characteristics.

The risks of the people can be defined according to the individual's role in the development. The experts are the major source of knowledge. Therefore, they must be able to communicate that knowledge, to devote time to the project, and to be cooperative. The knowledge engineer is responsible for the overall management and design of the system. They must be able to communicate with the expert, management, and the end users; to select appropriate software and programming techniques; and to devote a large amount of time. The end users are those individuals that will have to interact with the completed system. They must be willing to devote time not only to the development, but also to the testing of the system; to be receptive to the changes that the completed expert system will invoke; and to be cooperative and motivated about the system development. The management controls the funds for the project. Therefore, they must support the development, be receptive to the changes the completed system will invoke, not be skeptical of the results of a new technology, have reasonable expectations, and understand the objectives of the project.

The final category of the risk assessment is deployment. In order for an expert system to be successful, it must be effectively distributed and maintained. The critical considerations include: how easily can the system be introduced into the work environment, how will the system be maintained, can it be integrated with existing resources of the organization, will training be available to end-users.

Upon the completion of the feasibility study, a candidate application must be singled out as the project to be developed and the knowledge engineer must start preparatory work. Before the knowledge acquisition phase of the project can begin the knowledge engineer, the person that is responsible for the expert system development, must have an understanding of the problem area. This can be accomplished by reading text books and manuals relating to the subject area and examining case histories or documents. The knowledge engineer should know as much as possible about the knowledge domain before consulting with the experts in the field.

2.2.2 Knowledge Acquisition

The second phase of the development is the Knowledge Acquisition Phase. This phase is considered the most difficult phase of expert systems development. It is a cyclic process that includes collection, interpretation, and analysis of domain knowledge. The collection of knowledge is the process of retrieving knowledge from the domain experts and the documentation on the problem area. The interpretation of the knowledge is to identify key concepts, rules, and strategies. These key ideas are analyzed in order to form theories on the organization of the knowledge and problem-solving strategies. The objective is to obtain a complete and correct description of the expert's knowledge and the way that knowledge is handled. The success of the knowledge acquisition phase is dependent upon a cooperative team effort.

Retrieving or acquiring knowledge from the domain experts is accomplished through interviews and meetings. The general guidelines for effective fact-finding interviews include: be specific, do not interrupt, record information, listen to the way the expert uses the knowledge, and allow the expert to use familiar tools to represent knowledge. A variety of questioning methods can be used to obtain specific results depending on the personality of the expert. Those methods include (Hart 1986): allowing the expert to describe interesting or difficult cases that have occurred; allowing the expert to give a lists of characteristics and possible decisions based on those characteristics; giving the expert a goal and allowing the expert to specify the sets of evidence which are necessary to distinguish this goal from the other alternatives; allowing the expert to work backwards from a goal rather than forward from a set of characteristics; or allowing the expert to think out loud at work. Not only can a variety of questioning methods be used to obtain specific results, but a variety of interview methods can also be used to obtain specific results. These interview methods include (Allwood 1989): unstructured interviews, focused interviews, and case study interviews. The unstructured interviews allow the expert to talk generally about the whole problem area. The focused interviews concentrate on identifying the preliminary questions for specific goals. The case study interviews allow the expert to review and discuss key issues of past problems. Interviews can be conducted with individual experts or in a group setting. Best results will be obtained when the expert and elicitor work together as a team, using a method which both find helpful.

Once the collection of knowledge is complete, the interpretation and analysis of this knowledge begins. These stages should consider the following issues (Hart 1986):

- What are the inputs or problems?
- What are the outputs or solutions?
- Which types of inputs cause difficulties for the expert?
- How are the problems characterized?
- How are the solutions characterized?
- What sort of knowledge is used?

- How are problems or methods broken down into smaller units?

A later, more detailed, breakdown would answer detailed questions such as:

- What data are input; in what order and form?
- What are the interrelationships between data items?
- Which data might be missing?
- What assumptions does the expert make?
- What constraints does he have?
- What sort of inferences does he make?
- How does he form concepts and hypotheses?
- How do these relate to each other?
- How does the expert move from one state of belief to another?
- What are the causal relationships?
- Are there any logical constraints on the system?
- Which problems are easy, common, hard, interesting, etc?

The output of the interpretation and analysis stage is a conceptual knowledge model that is ready for design.

2.2.3 System Design

The next phase of the development is the system design. The objective of this phase is to determine the knowledge representation technique, inference technique, and expert system software; to develop a prototype; and to refine the expert system. Section 2.1

discussed the available knowledge representation and inference techniques. It is during this phase of the development that these techniques must be evaluated and the best technique for the problem must be selected. The selection of the expert system software will depend, in part, upon the knowledge representation and inference techniques selected. In addition, the cost, developer interface, and user interface of the software should be examined. Many expert system shells are available with different characteristics. The key is to find the one that is most useful for the problem at hand.

Once the knowledge representation technique, inference technique, and expert system software have been selected, the next step is to design a prototype. The objectives of the prototype preliminary development are to validate the expert system approach, to define the global strategy, to define the knowledge structure, and to validate the project. Once the objectives of the preliminary prototype development are met, the prototype should be made to represent a more formal expert system. The objectives of the final prototype are to represent to the end-users what the system will do and how the system will look. Therefore, an effective user interface must be developed. The keys to effective interface design are: Consistency, Clarity, and Control (Durkin 1994). The screens must be presented in a consistent manner, the material must be presented in a clear and concise manner, and the screens must be easy to control. Upon completion of the prototype, meetings should be held with the experts and end-users to receive suggestions for refinements. The final stage of the design phase is to incorporate these refinements and to cycle back through the design phase as needed.

2.2.4 Testing

The next phase of the expert system development is Testing. This phase includes system validation, verification and user acceptance. Verification and validation are utilized together to ascertain what the system knows, does not know, or knows incorrectly; ascertain the level of expertise of the system; determine if the system is based on a theory for decision making; and determine the reliability of the system. The system's results and reasoning process should resemble the expert's. Verification and validation can be done be using test cases and comparing the expert system's results with the expert's results. The user acceptance will be based on the ease of use of the system, clarity of questions, clarity of explanations, and presentation of results of the system. The user acceptance can be determined by questionnaires. The questionnaire should not only allow the user to rate the system, but should also allow the user to recommend better approaches for the system.

2.2.5 Documentation

The documentation phase of the development is really taking place over the entire length of the project. It should include the knowledge engineer's personal diary of the project development and all the material collected during the project for use in the development. Good organization of the documentation will not only ease in the development of the expert system, but will also ease in the preparation of final documentation of the system. The final documentation should include a final report, a glossary, the source code, a users guide, and a training and maintenance manual.

2.2.6 System Maintenance

The final phase of the development is system maintenance. However, this phase should be considered during the first steps of the development. It is important to consider who will be maintaining the system at the very beginning of the project. This decision should direct the design of the expert system. The key to system maintenance is complete and accurate documentation.

2.3 Knowledge-Based Expert Systems Applications

Research into artificial intelligence started in the late 1950s, but expert systems did not appear until the mid 1970s. A medical system, MYCIN, by Shortliffe in 1976, is often cited as the first, and certainly was a major contribution to general awareness of the topic. Similarly, the mineral exploration system, PROSPECTOR, illustrated the potential of the technique in engineering. In the construction industry, John Lansdown in 1982, introduced many people to the topic through a report on 'Expert Systems in the Construction Industry'.

Expert systems have now been used to solve a broad range of problems including: data interpretation, prediction, diagnosis of malfunctions, design, planning, monitoring, debugging and recommending repairs for malfunctions, instruction in how to solve problems, and control of system's behavior. These problem types match up well with the various functional areas of transportation and construction engineering which include: planning, design, fabrication, construction, inspection, maintenance and rehabilitation. In many of these tasks, engineers make extensive use of computers. However, many other tasks lack explicit numerical algorithms and are so complex or ill-defined that conventional computer tools are of limited use. Expert systems have great potential for solving such ill-structured problems.

2.3.1 Knowledge-Based Expert Systems in Transportation

Transportation engineering has been made more efficient in recent years through computer applications. Expert systems have been increasingly used on a variety of applications in transportation engineering. The following are examples of systems developed in the last three to four years. (Hess & Roddis 1994; Melhem et al. 1994) BFX (Bridge

Fabrication error Solution Expert System) is used to help design engineers and materials inspectors determine the extent of damage due to fabrication errors and specify the necessary repair solution. It was created to provide a unified repair procedure for the Kansas Department of Transportation (KDOT). SITE (Site Investigation and Training Expert Advisor) is used to assist in the assessment and preliminary investigation of suspected hazardous waste sites on proposed and existing highway projects. TANK (Tank Advisor and Knowledge Systems) is used to generate an appropriate preliminary site investigation strategy to determine the type and extent of contamination from underground fuel tanks. Both SITE and TANK are currently being used by the California Department of Transportation (Caltrans) (NCHRP 93). The Connecticut Department of Transportation (ConnDOT) currently uses an expert system, Pavement Rating and Analysis System (PRS), for pavement condition rating (NCHRP 93). The Illinois Department of Transportation (IDOT) is currently developing an expert system that will attempt to relate administrative policies from preventive maintenance to bridge replacement (NCHRP 93).

There are many expert systems being implemented and developed for the transportation industry (NCHRP 93). Many are still in the development stages, however, several are in actual use. The diversity in application is evident by the above examples. As the technology becomes more widely used and accepted, the amount of applications will also increase.

2.3.2 Knowledge-Based Expert Systems in Construction

Construction engineering has also been made more efficient in recent years through computer applications. Expert systems are becoming an effective tool in the construction industry to solve problems. SOILCON (Sole Exploration Consultant) is used to eliminate to some extent the uncertainty involved in subsurface exploration by evaluating known conditions of the site and recommending appropriate methods to continue explorations, if required. The system is designed to incorporate subsurface considerations into contract design, thereby reducing contractor contingencies (Arockiasamy 1992). SIGHTPLAN (Layout of Temporary Construction Facilities) is designed to assist project managers in their complex task of designing site layouts and updating the plan continually as project time progresses. It is currently in the development stages BERT (Brickwork Expert) is an interactive design aid that evaluates proposed designs for the brickwork cladding of a building. It critically reviews a submitted design form and AUTOCAD system and suggests improvements to the user for editing the drawing (Arockiasamy 1992).

Many more applications are available for the construction industry. The primary focus is on specific expert systems for specific needs of construction engineers. The development of these expert systems allow the engineers to address broader issues such as knowledge availability, decision-making strategies, design innovation, and education of personnel.

3.0 Bridge Construction Expert System Development

Section 2.2 discussed the general methodologies used for the development of expert system. This section discusses in detail the development of the Bridge Construction eXpert system (BCX). The development was divided into eight phases: (1) Problem Identification and Selection, (2) Feasibility Analysis, (3) Formation of Panels, (4) Definition of Goals, (5) Knowledge Acquisition, (6) Knowledge Engineering, (7) Validation and Verification, (8) Evaluation and Documentation. This development methodology has been specifically tailored to the Kansas Department of Transportation mission and needs. The development time schedule is shown in Figure 6.

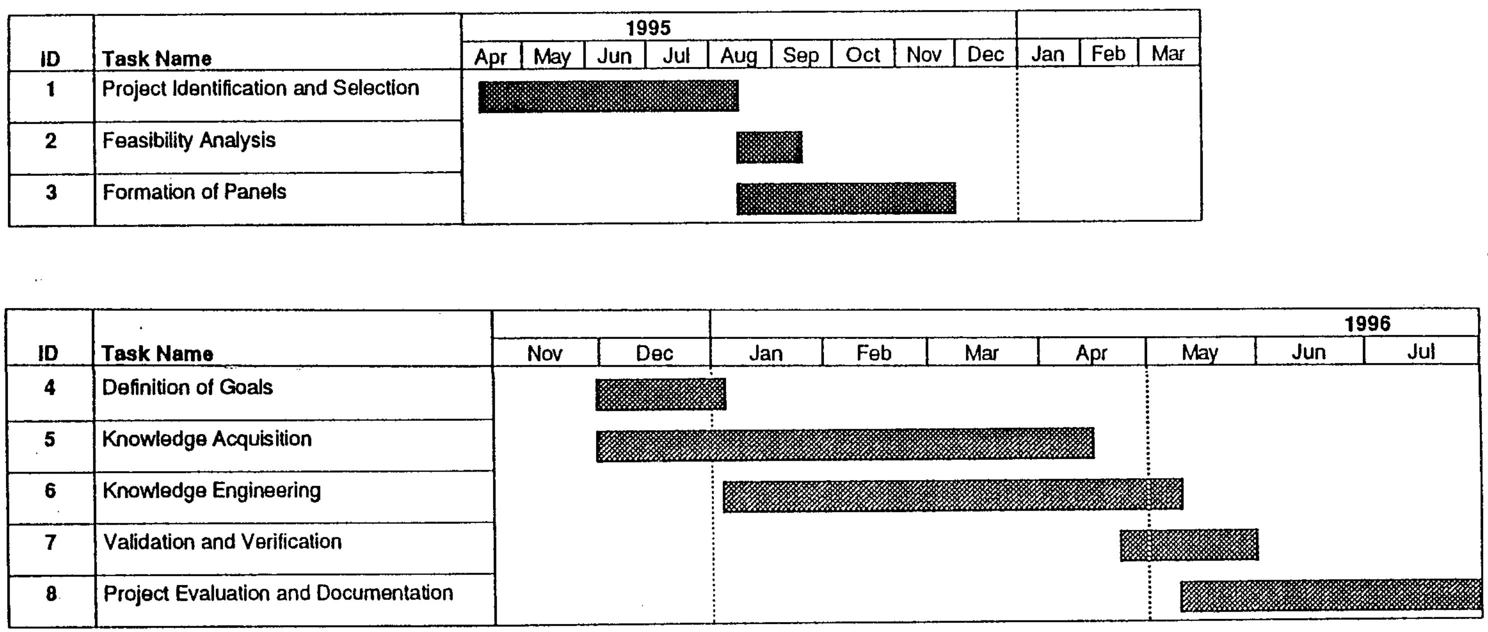

Figure 6. BCX Development Time Cycle

3.1 Problem Identification and Selection

The objective of this phase was to perform applicability assessment and generation of candidate applications for expert systems for KDOT. The research team met with engineers from the Bureau of Bridge Design, State Road Office, Bureau of Materials and Research, and Local Projects for the purpose of brainstorming and generating a list of possible applications. The candidate applications are summarized as follows:

- Bridge deck cracking - environmental effects on deck placement.
- Corrosion of bridge deck reinforcement - life prediction and repair efficiency.
- Bridge deck repairs - performance of overlays and epoxy-coated rebars.
- Bridge construction errors - recommended repairs and training.
- Highway layout - length of turning and acceleration lanes, and grade percentages.
- Highway layout - checking environmental codes, alignment choices, effect on economic development, wet lands, right-of-ways, etc.
- Cost/benefit ratios - acceptable designs within technical constraints.
- Prestressed concrete beams - acceptance criteria, quality control and quality assurance.
- Concrete slab placement - checklist for field inspection before pouring.
- Inspection of rebar epoxy coating - interpretation of holiday detector data.
- Scour problems - inspection aid for what to look for, analysis of ill-determined situations, and interface to scour software.
- Pile driving - criteria for number of blows and penetration depth.

- Debris collection around bridge piers - remedial actions.
- Fatigue of bridges - a surrogate tool for appropriate repairs.
- Asphalt pavement construction - assistance in field inspection of asphalt.
- Concrete pavement - subsurface drainage.

Most of these applications are suitable for expert system development. However, the bridge construction errors application was selected as the most appropriate candidate application to investigate. The main criteria for selection was the organizational commitment, evaluation of payoff, urgency and benefits, goals and expectations, technical suitability, and availability of expertise. A bridge construction expert system was an obvious extension to the bridge fabrication error solution expert system (BFX) that was developed by a joint University of Kansas and Kansas State University research project (Hess & Roddis 1994; Melhem et al. 1994). That project was successfully completed and its outcome was presented to the bridge and structures communities. In addition, there was a real need to establish allowable construction tolerances to be used by construction engineers and inspectors in the field. There is an ever increasing number of young engineers and inspectors, while the number of experts is rapidly decreasing. It was of vital importance to obtain the knowledge from these experts. The technical suitability and the availability of expertise are discussed further in the next section.

3.2 Feasibility Analysis

The main objective of the feasibility analysis was to determine the likelihood of success. The success of an application can be estimated by examining the project requirements and the project risks as discussed in Section 2.2.1. Because this is not the first expert system development research project for the Kansas Department of Transportation, the proper resources and deployment procedures have previously been established. Therefore, the feasibility study for this project analyzed only the suitability of the problem and the availability of expertise.

3.2.1 Suitability of the Problem

The main features of an expert system are that they use heuristics and that they are data driven rather than procedure driven. Therefore, a suitable problem must be of this nature. Errors occur during the construction of nearly every bridge. Minor errors can result in catastrophic effects on the completed structure. Therefore, it is important that these errors are properly identified and corrected at an early stage. However, there are currently no guidelines for many of these errors. Generally, they must be solved by experienced bridge engineers, inspectors, and contractors. Over the years, these individuals have acquired a knowledge of acceptable tolerances in the construction of bridges. They use heuristics or rules of thumb to solve the majority of problems. Their solutions are based on the data of the error rather than a procedure or algorithm that could be used in a conventional computer program. Thus, it was determined that the bridge construction errors application was a very suitable application of expert system technology.

3.2.2 Availability of Expertise

In order for the development of an expert system to be successful, there must be experts in the problem area and these experts must be willing to participate. Fortunately, there have been two previous successful expert system projects completed by this research team for the Bridge Design Office at KDOT. The success of these projects has motivated engineers within KDOT to participate in future projects. There were a number of construction experts from the bridge and construction offices of KDOT. In addition, there were a number of consultants and contractors that are considered experts in the field of bridge construction. These experts committed their time to the development of a bridge construction expert system.

3.3 Formation of Panels

An expert system is only as good as the knowledge which is in it, and this implies the knowledge which has been elicited from the experts (Hart 1986). The successful development of this expert system was dependant upon the access to and the cooperation of experts in the problem domain. However, the most complete knowledge base cannot be successful without considering the end users and the end usage of the expert system. Therefore, two panels were formed for the development of this expert system. Each panel consisted of seven individuals, including design engineers, field engineers, inspectors, consulting engineers and contractors, as shown in Appendix D.

3.3.1 Panel of Experts

The Panel of Experts (PoE) was formed with the cooperation of KDOT. The members of this panel consisted of two bridge engineers, three construction engineers, one contractor, and one consulting engineer. The Panel of Experts served as the primary source of domain expertise. Table 3 shows the time commitment that each member of this panel made.

Participation	**Number**	**Length**
Panel Meeting	3	4 hours
Verification Meeting	2	4 hours
Personal Interview	3/member	2 hours
Response to Questionnaire	2	2 hours
Write Reviews of system	3	2 hours

Table 3. Panel of Experts Time Commitment

The responsibilities of this panel included determining the scope of the expert system, providing input for construction error solutions, verifying the knowledge of the expert system, and reviewing the completed expert system.

3.3.2 Panel of Users

The Panel of Users (PoU) for this project actually included a number of individuals considered as experts in the field of bridge construction. The members of this panel also consisted of three construction engineers, two bridge design engineers, one contractor, and one consulting engineer. The Panel of Users served as the secondary source of domain expertise. In addition, the Panel of Users was responsible for determining the user interface, verifying the knowledge, and reviewing the completed expert system. The time commitment made by the members of this panel is shown in Table 4.

Participation	Number	Length
Panel Meeting	1	4 hours
Verification Meeting	2	4 hours
Personal Interview	2/member	2 hours
Response to Questionnaire	2	2 hours
Write Reviews of system	3	2 hours

Table 4. Panel of Users Time Commitment

3.4 Definition of Goals

Once the panels were formed, the members were asked to identify the goals of the project: (1) purpose of the system, (2) scope and boundaries, (3) usage and usefulness, (4) target audience and expected end users, and (5) advantages and benefits.

3.4.1 Purpose of the System

One of the first responsibilities of the Panel of Experts was to determine the purpose of the system. One of the main reasons that this problem was selected was because of the increasing number of young engineers and inspectors in the field. These individuals have not had the experience to deal with the majority of construction errors. They feel uneasy about even the smallest error because they do not understand how the error will effect the completed structure. Therefore, it was decided that one of the main objectives of this expert system should be for training. Furthermore, the panel determined that the training could be in the form of a tutorial or a problem solving session. In turn, the problem solving side could stand alone for more experienced engineers and inspectors. Thus, the purpose of the system was defined as a training and problem solving tool for young and somewhat experienced engineers and inspectors.

3.4.2 Scope and Boundaries

The second responsibility of the Panel of Experts was to determine the scope of the expert system. A large number of construction problems can and do occur. To limit the scope, the first step was to examine existing case histories to determine the frequency with which a particular type of error occurs. Forty-two cases were submitted by the panel members. These cases were examined and classified by the error member. Since many construction errors and solutions are never documented, the experts were asked to determine the most important construction errors. The experts agreed that the most important construction errors are those involving the substructure. If errors occur during the construction of the substructure, construction comes nearly to a halt, resulting in costly delays while the engineers determine the effect on the structure. More importantly, foundation errors, if not identified and corrected, can be covered with soil and not detected until problems occur in the superstructure construction or after the entire bridge is built. Because of the potentially catastrophic effects of these errors, it was decided that the scope of the expert system should be limited to pier footing errors, in Metric or English units, to include pile footings, pile bents, spread footings, and cofferdams and exclude drilled shafts. Upon successful completion of this expert system, the entire substructure and superstructure units would be covered in a series of subsequent projects. Meetings with the Panel of Users confirmed the limited scope of the system.

3.4.3 Usage and Usefulness

Both panels were used to determine the expected usage and usefulness of the system. As discussed previously, the purpose of the system was to serve as a training and problem solving tool for young, as well as, somewhat experienced engineers and inspectors. The system will be used by new engineers and inspectors more as a training tool. It is foreseen that the system will be integrated into the established training procedure. In addition, these engineers and inspectors will use the system as a reference and a problem solving aid as they gain more experience. Once the system has been tested and successfully validated by the bridge design office, it will be available in every field office and may be available to engineers and inspectors outside of KDOT. The usefulness of the system is that the training side will prevent errors from occurring and the problem side will reduce the time spent solving relatively simple problems.

3.4.4 Target Audience and Expected End Users

Again, both panels were used to determine the target audience and expected end users. It was decided that the system would be designed for a target audience with at least five years of experience so that they are familiar with the construction terminology. Within KDOT, this would be ET or ET Senior personnel. The expected end users as previously mentioned would be young and experienced engineers and inspectors.

3.4.5 Advantages and Benefits

There are two classifications of advantages and benefits; those of creating the expert system and those of using the expert system. The creation of an expert system has the potential to provide better allocation of scarce resources, more consistent quality of solutions, and improved personnel productivity and performance, leading to improved efficiency and reliability at reduced cost. The benefit to KDOT is to utilize established expert system technology to address the transportation needs of the State of Kansas. Particularly, the creation of this expert system permitted continuity in the technology transfer of expert system methodology from a research to a practical environment.

The use of an expert system designed as an expert consultant allows a novice or less experienced person to learn from the interaction with the expert system. In this capacity, such a system can be regarded as a training tool so that the learning person would not have to refer to his supervisor, inspector, or senior designer every time there is a conflict or problem on the job. For routine problems and typical situations that occur frequently, the expert system can quickly recommend the correct solution. Experts can then devote their time to handle more complicated problems and more complex situations. The use of an expert system has the potential to achieve better and less costly design, construction and erection of highway bridges to meet the needs of the people of Kansas.

3.5 Knowledge Acquisition

Knowledge Acquisition entails extracting domain knowledge from the literature, documentation of current procedures, and interviews of the experts. Examples were gathered from: (1) expert's questionnaires, (2) historical case records, and (3) simulated results for hypothetical situations. About two third of these examples were used to develop the problem-solution knowledge base and the remaining third were used to verify the system performance. The knowledge included in the training knowledge base was extracted from: (1) interviews of the experts, (2) KDOT Construction Manual, (3) KDOT Bridge Design Manual, and (4) KDOT Standard Specifications for State Road and Bridge Construction.

The domain knowledge extraction can be best described by a chronologic record of this phase of the development. Figure 7 shows the time table for the domain knowledge extraction. As shown, the knowledge was obtained from panel meetings followed by interviews and concluded with additional panel meetings.

The first meeting of the Panel of Experts was held at an early stage of the project (November 30, 1995). The knowledge acquisition objectives of this meeting were to identify typical bridge construction problems and to plan for data collection. The discussion of the seven experts covered a very broad area of bridge construction errors. Therefore, it was decided that the best method for data collection would be for each member of the panel to submit a list of previous or potential construction errors. The research team compiled the list and identified overlapping items from each list as shown in Figures 8, 9, and 10. In addition, the experts submitted reports from past cases. These cases were also compiled by the research team and are shown in Appendix E.

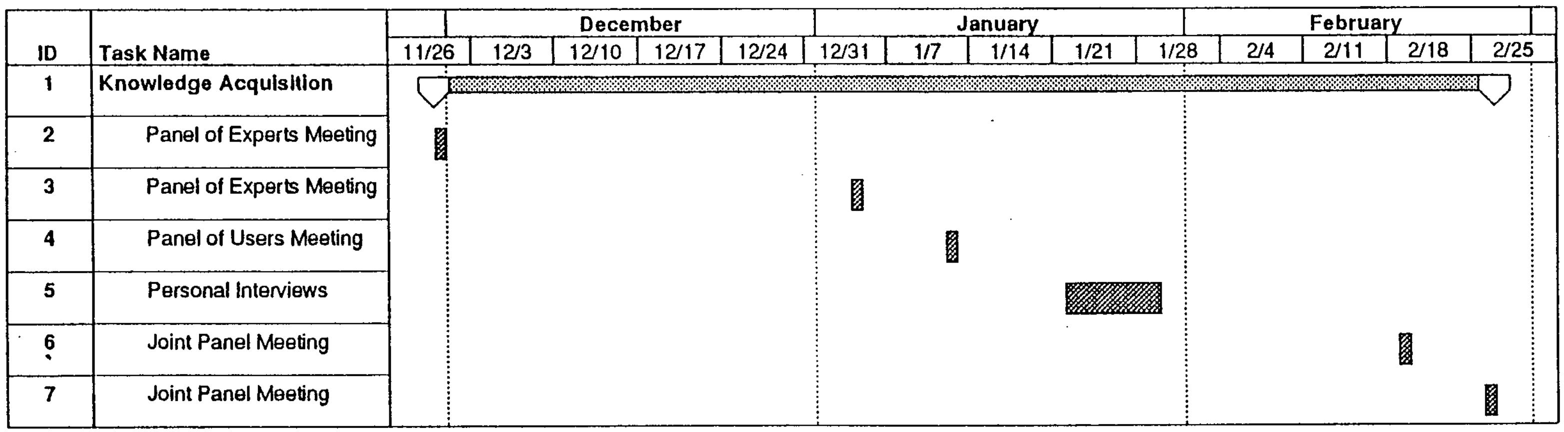

Figure 7. Knowledge Acquisition Time Cycle

IDENTIFIED BY*	SUBSTRUCTURE		Frequency
CKE	POSITION:		
CKE		Out of Line	
CKE		Not on Station	
CKE		Out of Plumb	
CKE		Span Length Deviation	✓
CKE		Final Elevation	
KFH	FOUNDATION:		
KFH		Piling	
KFH/CKE/RBT		*Location*	✓✓✓✓✓
KFH/CKE/RBT		*Orientation*	✓✓
KFH/CKE/RBT		*Batter*	
KFH		*Capacity*	
KFH/CKE		*Minimum Penetration*	✓
CKE/RBT		*Bearing*	
KFH		Spread Footing	
KFH		*Overbreakage*	
CKE		*Void Detection*	✓
RBT		*Location*	✓✓
KFH		Raise/lower footing	
KFH/RBT		*Fissures/seams*	✓
KFH		*Location*	
KFH		Drilled Shaft	
KFH		*Location*	
KFH		*Rock Socket*	
KFH		*Wet/Dry Placement*	
KFH		*Debris*	
KFH/RBT		*Water Inflow*	✓
KFH		Cofferdams	
KFH		*Design calc. & details*	
KFH/RBT		*Seal*	
KFH/RBT		*Water inflow*	✓
KFH		*Removal*	
KFH	ABUTMENTS:		
KFH/RBT		Location	
KFH		Drainage	
KFH		Backfill Compaction	
KFH	COLUMNS:		✓
KFH		Location	✓
KFH		Reinforcement	
KFH		Splices	
KFH		Construction Joints	
KFH	PIER CAPS:		✓✓✓✓
KFH		Location of Bearing	✓
KFH		*Edge Distance*	
KFH/CKE		*Eccentric Loading*	✓
RBT		*Set without regard to Temperature*	✓
KFH/CKE		Elevation on Bearing	✓✓✓
KFH/RBT		Pre-formed/Cast-in/Drilled anchor bolt holes	✓✓✓✓

*CKE: Charlie K. Ellis, KFH: Ken F. Hurst, RBT: Robert B. Thom

Figure 8. Potential Substructure Construction Errors

IDENTIFIED BY*	SUPERSTRUCTURE			Frequency
CKE	TOLERANCE STACKUP:			
CKE		Span Deviations		✓
CKE		Total Length Variations		
CKE		Stiffener Variations in Relation to Bearing		✓
CKE		Finish Girder Elevation		
CKE		Shear Stud Clearance in Deck		
CKE			*To Top of Deck*	
CKE			*To Bottom of Deck*	
KFH	TYPES:			
KFH		Cast-in-Place		
KFH/RBT			*Falsework/Formwork*	✓✓
KFH			*Placement Sequence*	
KFH			*Camber*	
KFH			*Equipment Breakdown/header location*	
KFH		Prestressed Concrete		
KFH			*Shop Drawings/Erection*	
KFH		Structural Steel		✓✓✓✓
KFH			*Shop Drawings/Erection*	✓
KFH/RBT			*Bolting*	✓✓✓✓
KFH			*Stud Length*	✓
KFH			*Fillet Depth*	
KFH		Post-Tensioned		
KFH			*Shop Drawings/Erection*	
KFH			*Falsework/Erection Sequence*	
KFH	DECKS:			
KFH/CKE		Profile Tolerance		
KFH/CKE		Cross-slope Tolerance		
KFH		Curing Time		
KFH		Construction Live Load		
CKE		Minimum Thickness		
CKE		Rebar Clearance		
KFH	EXPANSION JOINTS:			✓
KFH		Profile Transition		
KFH		Geometric Fit-up		✓✓✓
KFH	RAILS:			
KFH		Geometric Tolerances		
KFH		Guardrail Attachment		

*CKE: Charlie K. Ellis, KFH: Ken F. Hurst, RBT: Robert B. Thom

Figure 9. Potential Superstructure Construction Errors

IDENTIFIED BY*	MISCELLANEOUS STRUCTURES		Frequency
KFH	MSE & RETAINING WALLS:		
KFH		Foundation	
KFH		Backfill	
KFH		Drainage	
KFH		Compaction	
KFH		Location/Alignment Tolerance	
KFH	CULVERTS:		
KFH		Foundation Stabilization	
KFH		Construction Joints	
KFH		Falsework/Formwork	
KFH		P/C Joint	
KFH		Flowline Tolerance	
KFH		Location Tolerance	
KFH	OTHER:		
KFH		Light Towers	
KFH		*Location*	
KFH		Signing Structures	
KFH		*Location*	
KFH		*Elevation*	

*CKE: Charlie K. Ellis, KFH: Ken F. Hurst, RBT: Robert B. Thom

Figure 10. Potential Miscellaneous Construction Errors

The second meeting of the Panel of Experts was held about five weeks later (January 4, 1996). This meeting concentrated on identifying the scope and boundaries of the system. The list of potential construction errors and the submitted case histories were used to identify the most critical errors. Figures 11 and 12 show the distribution of cases for the substructure and the superstructure. Of the forty-two cases that were submitted, twenty three of those cases were related to the substructure and nineteen to the superstructure. Of those cases related to the substructure, seven concerned the pier footings. It was beginning to become evident by the frequency of the cases submitted that pier footings should be the scope of the project. In addition, the experts identified the substructure and especially the pier footings as the most critical error in the construction phase. If errors occur during the construction of the pier footings, construction on that pier is stopped until a solution for that error can be determined. This results in a loss of time and money for the contractor as well as the State of Kansas. Worse yet, if those errors are not properly identified and corrected, they are covered and may not be discovered until errors arise in the superstructure construction or until the performance of the bridge is questioned. Therefore, the efforts of knowledge acquisition concentrated on pier footings from that point. The next step was to identify the areas within pier footings to be covered. A preliminary flow chart of the expert system was developed. This flow chart was used to identify and address hypothetical cases during the panel meetings and interviews. It was revised many times and Figure 13 shows the final version of the flow chart. As can be seen from the chart, the pier footing expert system covers pile footings, pile bents, spread footings, and cofferdams. Drilled shafts were excluded from the system scope at this time because there is enough information within the

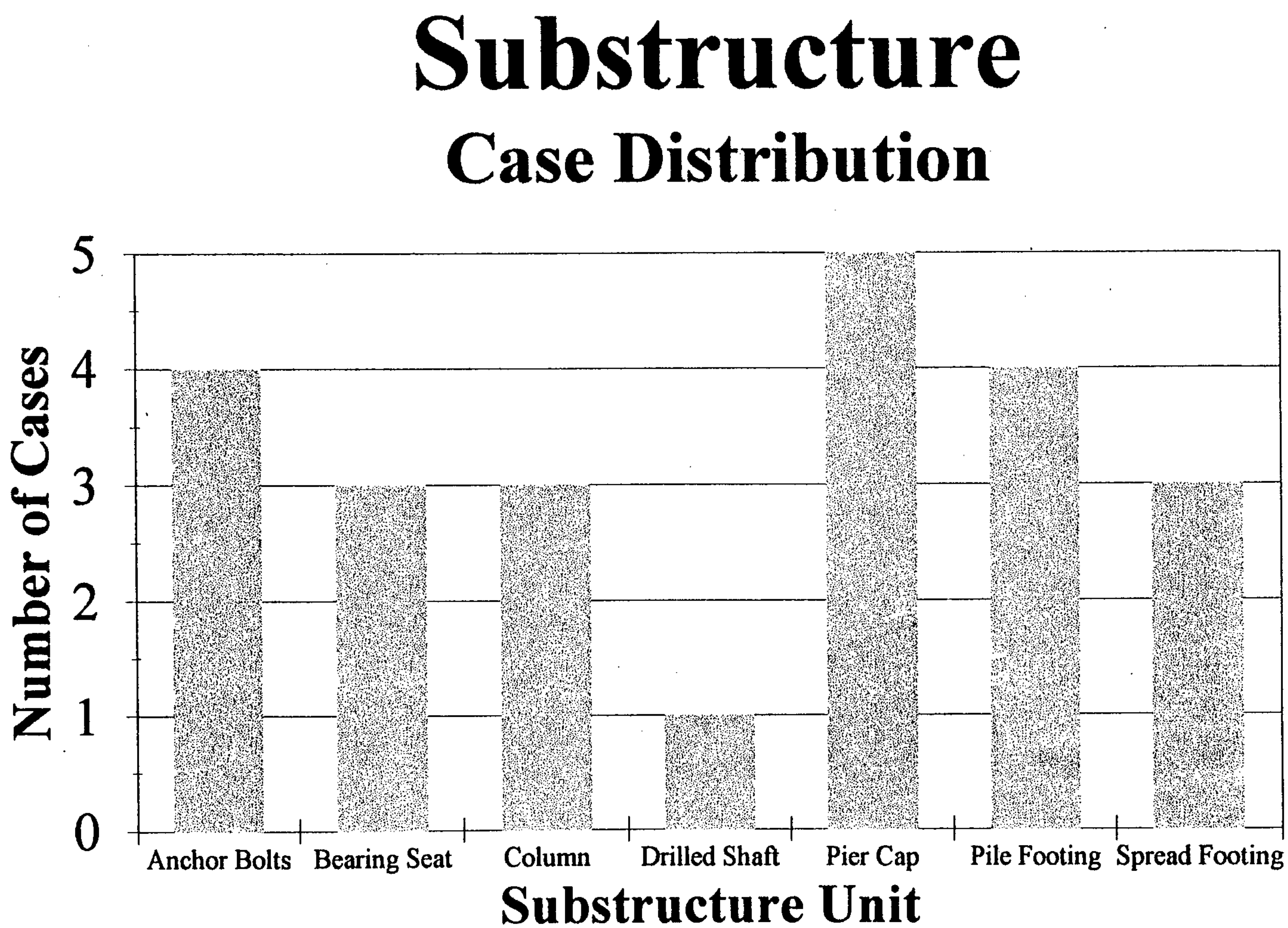

Figure 11. Substructure Case Distribution

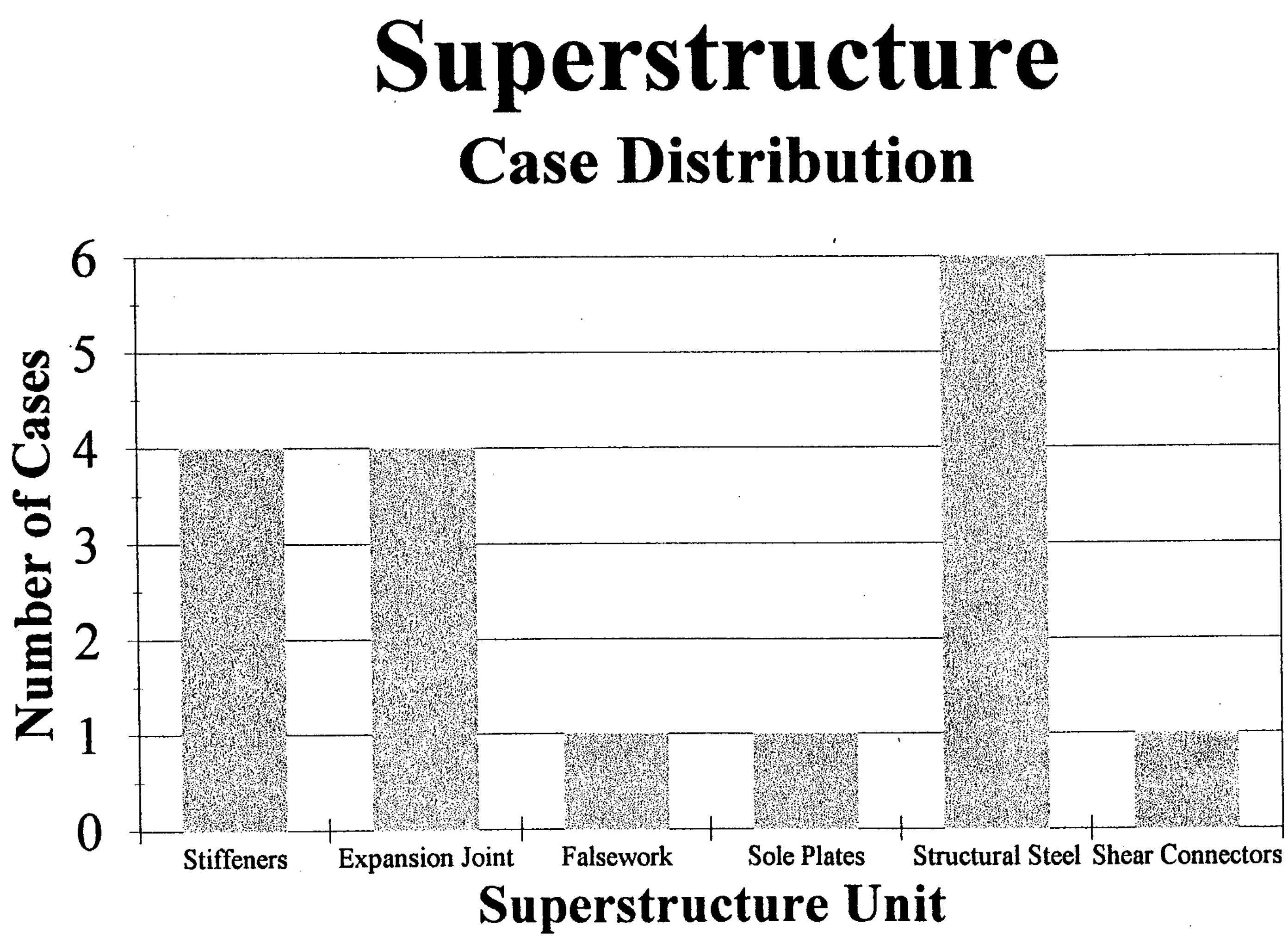

Figure 12. Superstructure Case Distribution

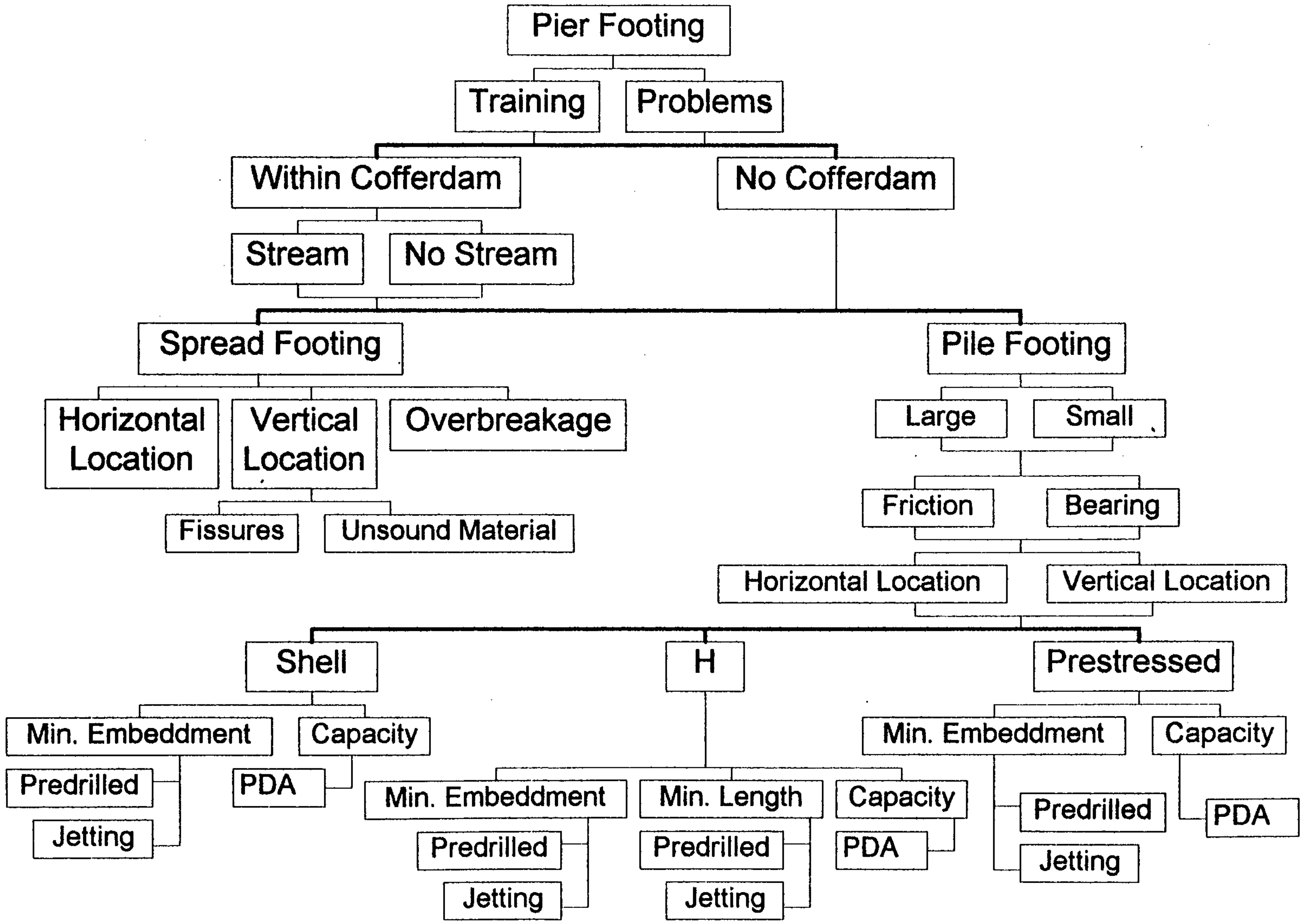

Figure 13. Pier Footing Expert System Flow Chart

specifications on drilled shafts and because of the limited time frame of the project.

The Panel of Users were used as a secondary source of knowledge. The first meeting with this panel was held on January 12, 1996. This meeting was used to expand on the information gathered from the Panel of Experts. The flow chart was examined and revised. As a side note, several terminology differences between design and construction were identified. It is interesting to note that "short" does not mean the same to a construction engineer as to a design engineer. The first flow chart had identified either "short" or "long" pile as being one of the considerations for the pile footing problem solution module. The Panel of Experts defined a short pile as a pile that is fifteen to twenty feet long, and a long pile as a pile that is more than twenty feet long. However, during the discussion at the Panel of Users it was obvious that this definition was not what they use. Short was defined by the construction engineers to mean that if a pile was to be driven to a certain depth (for example 35 feet) and in reality the pile could not be driven that much (say 25 feet), then the pile is considered short. So it was interesting to note the terminology differences that could make discussion between field engineers and bridge design engineers misleading. Only meetings of this type allow these differences to be identified and clarified.

The next step in the domain knowledge extraction was to interview members of both panels. Eight of the fourteen panel members were interviewed and each interview lasted between two and four hours. These interviews were used to further refine the flow chart, to compile a list of terms and definitions, to collect additional problem cases, and to determine the training module topics.

The other source of knowledge was the current literature and documentation in the field of construction. Information on pier footings was compiled from the KDOT Construction Manual, Bridge Design Manual, and Standard Specifications for State Road and Bridge Construction. All of the extracted knowledge was classified and documented with the appropriate reference and section number in that reference.

This knowledge and a preliminary prototype were then presented during joint meetings of the panels (February 19 and 26, 1996). These meetings served to eliminate contradictory information and to allow the panel members to come to a consensus on several construction error tolerances. In addition, the preliminary prototype was evaluated. The prototype evaluation will be discussed in the following section. The final representation of the knowledge that was used for the knowledge engineering is shown in Table 5 through Table 8.

CASE	Cofferdam	Stream	Footing Type	Type of Problem	Cause of Error	Distance of Mislocation	Depth to Sound Material	Conclusions & Advice
AMS101	yes		Spread Footing	Horizontal Location	Cofferdam Interference	< 300 mm (1 foot)		REPAIR 1
AMS102	yes		Spread Footing	Horizontal Location	Cofferdam Interference	> 300 mm (1 foot)		REPAIR 2
AMS103			Spread Footing	Horizontal Location	Incorrect Excavation			REPAIR 3
AMS104			Spread Footing	Vertical Location	Fissures			REPAIR 4
AMS105	yes	yes	Spread Footing	Vertical Location	Bedrock at a higher elevation than anticipated			REPAIR 5
AMS106	yes	no	Spread Footing	Vertical Location	Bedrock at a higher elevation than anticipated			REPAIR 6
AMS107	no		Spread Footing	Vertical Location	Bedrock at a higher elevation than anticipated			REPAIR 6
AMS108			Spread Footing	Vertical Location	Unsound Material/Bedrock Lower than anticipated		< 450 mm (18 inches)	REPAIR 7
AMS109			Spread Footing	Vertical Location	Unsound Material/Bedrock Lower than anticipated		> 450 mm (18 inches)	REPAIR 8
AMS110			Spread Footing	Vertical Location	Unsound Material/Bedrock Lower than anticipated		UNKNOWN	REPAIR 9
AMS111			Spread Footing	Overbreakage	Incorrect Excavation			REPAIR 3

REPAIR 1:	The spread footing problem was caused by a mislocated cofferdam. The footing may be poured against the cofferdam if needed. However, with waler rings inside the cofferdam, you may create additional problems. Another possible solution is to shift the footing and the reinforcing steel for the footing. However, the position of the column and thus the column steel should be maintained. Consult District Engineer for other solutions.
REPAIR 2:	The spread footing problem was caused by a mislocated cofferdam. The mislocation is too large to recommend a solution to the problem. Call the District Engineer for appropriate procedure.
REPAIR 3:	The spread footing problem was caused by an incorrect excavation or overbreakage. Excavate so that the footing can be placed in the correct location. Cut the excess excavation to neat lines and backfill with concrete. Consult District Engineer for other solutions.
REPAIR 4:	The spread footing problem was caused by fissures. Remove all loose material to a solid condition and backfill with concrete.
REPAIR 5:	The spread footing problem was caused by the bedrock being encountered at a higher elevation than anticipated. Because the bridge is over a stream, the bottom of the footing should be a minimum of 2 meters(6 feet) below the stream bed. If this depth has been reached, one possible solution is to shorten the column. However, such changes to the substructure design should not be made without consulting the Bridge office. First consult the District Engineer for appropriate solution.
REPAIR 6:	The spread footing problem was caused by the bedrock being encountered at a higher elevation than anticipated. Because the bridge is not over a stream, the depth of the footing is not as critical because scour is not a concern. One possible solution is to place the footing at this elevation and shorten the column. However, such changes to the substructure design should not be made without consulting the Bridge office. First consult the District Engineer for appropriate solution.
REPAIR 7:	The spread footing problem was caused by unsound material or the bedrock not being encountered at the elevation anticipated. Sound material was found within 450mm(18in). 1. Maintain the footing minimum embedment of 150 mm (6in) in rock and 300mm (1 ft) in shale. 2. Thicken the footing, but maintain the reinforcing steel mat elevation as shown on the plans.
REPAIR 8:	The spread footing problem was caused by unsound material or the bedrock not being encountered at the elevation anticipated. Sound material was not found within 450mm(18in). Consult District Engineer for appropriate solution.
REPAIR 9:	The spread footing problem was caused by unsound material or the bedrock not being encountered at the elevation anticipated. Determine the depth to sound material. If the depth to sound material is greater than 450mm (18in): Consult District Engineer for appropriate solution. If the depth to sound material is less than or equal to 450mm(18in): 1. Maintain the footing minimum embedment of 150mm(6in) in rock and 300mm (1 ft) in shale. 2. Thicken the footing, but maintain the reinforcing steel mat elevation as shown on the plans.

Table 5. Spread Footing Knowledge Representation and Repair Procedures

CASE	Footing Type	Type of Problem	Cause of Error	Horizontal Distance to Correct Position	Edge Distance from actual pile	Pile Diam. /Width	Actual Pile Spacing	Specified Length of Pile	Conclusions & Advice
AMS112	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <20mm/1m (1/4"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 10
AMS113	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <10mm/1m (1/8"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 10
AMS114	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <20mm/1m (1/4"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 11
AMS115	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <10mm/1m (1/8"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 11
AMS116	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <20mm/1m (1/4"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 12
AMS117	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <10mm/1m (1/8"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 12
AMS118	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <20mm/1m (1/4"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 13
AMS119	Pile Footing	Horizontal Location	Staking Error/Drift	< 150 mm (6") & <10mm/1m (1/8"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	>10.6 m (35')	REPAIR 13
AMS120	Pile Footing	Horizontal Location	Staking Error/Drift	> 150 mm (6")	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 14
AMS121	Pile Footing	Horizontal Location	Staking Error/Drift	> 150 mm (6")	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 15
AMS122	Pile Footing	Horizontal Location	Staking Error/Drift	> 150 mm (6")	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 16
AMS123	Pile Footing	Horizontal Location	Staking Error/Drift	> 150 mm (6")	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 17
AMS124	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <20mm/1m (1/4"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 18
AMS125	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <10mm/1m (1/8"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 18
AMS126	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <20mm/1m (1/4"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 19
AMS127	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <10mm/1m (1/8"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 19
AMS128	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <20mm/1m (1/4"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 20
AMS129	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <10mm/1m (1/8"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths	>10.5 m (35')	REPAIR 20
AMS130	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <20mm/1m (1/4"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	< 10.5 m (35')	REPAIR 21
AMS131	Pile Footing	Horizontal Location	Deflected	< 150 mm (6") & <10mm/1m (1/8"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths	>10.6 m (35')	REPAIR 21
AMS132	Pile Footing	Horizontal Location	Deflected	> 150 mm (6")	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 22
AMS133	Pile Footing	Horizontal Location	Deflected	> 150 mm (6")	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 23
AMS134	Pile Footing	Horizontal Location	Deflected	> 150 mm (6")	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 24
AMS135	Pile Footing	Horizontal Location	Deflected	> 150 mm (6")	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 25
AMS136	Pile Bent	Horizontal Location	Staking Error/Drift	< 50 mm (2") & <10mm/1m (1/8"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 10
AMS137	Pile Bent	Horizontal Location	Staking Error/Drift	< 50 mm (2") & <10mm/1m (1/8"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 11
AMS138	Pile Bent	Horizontal Location	Staking Error/Drift	< 50 mm (2") & <10mm/1m (1/8"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 12
AMS139	Pile Bent	Horizontal Location	Staking Error/Drift	< 50 mm (2") & <10mm/1m (1/8"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 13
AMS140	Pile Bent	Horizontal Location	Staking Error/Drift	> 50 mm (2")	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 14
AMS141	Pile Bent	Horizontal Location	Staking Error/Drift	> 50 mm (2")	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 15
AMS142	Pile Bent	Horizontal Location	Staking Error/Drift	> 50 mm (2")	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 16
AMS143	Pile Bent	Horizontal Location	Staking Error/Drift	> 50 mm (2")	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 17
AMS144	Pile Bent	Horizontal Location	Deflected	< 50 mm (2") & <10mm/1m (1/8"/1')	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 18
AMS145	Pile Bent	Horizontal Location	Deflected	< 50 mm (2") & <10mm/1m (1/8"/1')	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 19
AMS146	Pile Bent	Horizontal Location	Deflected	< 50 mm (2") & <10mm/1m (1/8"/1')	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 20
AMS147	Pile Bent	Horizontal Location	Deflected	< 50 mm (2") & <10mm/1m (1/8"/1')	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 21
AMS148	Pile Bent	Horizontal Location	Deflected	> 50 mm (2")	> 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 22
AMS149	Pile Bent	Horizontal Location	Deflected	> 50 mm (2")	> 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 23
AMS150	Pile Bent	Horizontal Location	Deflected	> 50 mm (2")	< 230 mm (9")		> 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 24
AMS151	Pile Bent	Horizontal Location	Deflected	> 50 mm (2")	< 230 mm (9")		< 750 mm (2'-6") or 2.5 pile diameters/widths		REPAIR 25

Table 6. Pile Footing and Pile Bent Knowledge Representation: Horizontal Location Problems

REPAIR 10:	The horizontal mislocation of the pile is within the Specifications 704.04d. In addition, the mislocation does not create an edge distance or a pile spacing problem. Consult District Construction Engineer for any additional recommendations.
REPAIR 11:	The horizontal mislocation of the pile and the edge distance are within the specifications. However, the mislocation created a pile spacing problem. Consult the District Construction Engineer for the appropriate solution.
REPAIR 12:	The horizontal mislocation of the pile and the pile spacing are within the specifications. However, the mislocation created an edge distance problem. Consult the District Construction Engineer for the appropriate solution.
REPAIR 13:	The mislocation of the pile is within specifications. However, the mislocation created a pile spacing and edge distance problem. Consult the District Construction Engineer for the appropriate solution.
REPAIR 14:	The mislocation of the pile is not within specifications. However, the pile spacing and edge distance specifications have been met. Consult the District Construction Engineer for the appropriate solution.
REPAIR 15:	The mislocation of the pile is not within specifications. Due to this mislocation the pile spacing specification has also been violated. However, the edge distance specification is met. Consult the District Construction Engineer for the appropriate solution.
REPAIR 16:	The mislocation of the pile is not within specifications. Due to this mislocation the edge distance specification has also been violated. However, the pile spacing specification is met. Consult the District Construction Engineer for the appropriate solution.
REPAIR 17:	The mislocation of the pile, the pile spacing and the edge distance specifications have all been violated. Consult the District Construction Engineer for the appropriate solution.
REPAIR 18:	The mislocation of the pile is within the specifications. In addition, the mislocation does not create an edge distance or a pile spacing problem. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult District Construction Engineer for any additional recommendations.
REPAIR 19:	The mislocation of the pile and the edge distance are within the specifications. However, the mislocation created a pile spacing problem. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 20:	The mislocation of the pile and the pile spacing are within the specifications. However, the mislocation created an edge distance problem. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 21:	The mislocation of the pile is within specifications. However, the mislocation created a pile spacing and edge distance problem. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 22:	The mislocation of the pile is not within specifications. However, the pile spacing and edge distance specifications have been met. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 23:	The mislocation of the pile is not within specifications. Due to this mislocation the pile spacing specification has also been violated. However, the edge distance specification is met. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 24:	The mislocation of the pile is not within specifications. Due to this mislocation the edge distance specification has also been violated. However, the pile spacing specification is met. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.
REPAIR 25:	The mislocation of the pile, the pile spacing and the edge distance specifications have all been violated. Since the piles were suspected to have been deflected, predrilling or jetting may be needed. Consult the District Construction Engineer for the appropriate solution.

Table 7. Pile Footing and Pile Bent Repair Procedures: Horizontal Location Problems

CASE	Stream	Footing Type	Pile Resistance	Type of Problem	Cause of Error	Specified Length of Pile	Scour Line	Depth Below Scour Line	Vertical Dist. to Corr. Pos.	Conclusions & Advice
AMS152	yes	Pile Bent		Vertical Location	Embedment		yes	>5 m (17')		REPAIR 26
AMS153	yes	Pile Bent		Vertical Location	Embedment		yes	<5 m (17')		REPAIR 27
AMS154	yes	Pile Bent		Vertical Location	Embedment		no			REPAIR 27
AMS155	no	Pile Bent		Vertical Location	Embedment				<20% length or 2 m (6')	REPAIR 28
AMS156	no	Pile Bent		Vertical Location	Embedment				>20% length or 2 m (6')	REPAIR 29
AMS157		Pile Bent	Friction	Vertical Location	Capacity					REPAIR 30
AMS158		Pile Bent		Vertical Location	Length	< 4.5 m (15')				REPAIR 31
AMS159		Pile Bent		Vertical Location	Length	> 4.5 m (15')				REPAIR 32
AMS160	yes	Pile Footing		Vertical Location	Embedment		yes	>5 m (17')		REPAIR 26
AMS161	yes	Pile Footing		Vertical Location	Embedment		yes	<5 m (17')		REPAIR 27
AMS162	yes	Pile Footing		Vertical Location	Embedment		no			REPAIR 27
AMS163	no	Pile Footing		Vertical Location	Embedment				<20% length or 2 m (6')	REPAIR 28
AMS164	no	Pile Footing		Vertical Location	Embedment				>20% length or 2 m (6')	REPAIR 29
AMS165		Pile Footing	Friction	Vertical Location	Capacity					REPAIR 30
AMS166		Pile Footing		Vertical Location	Length	< 4.5 m (15')				REPAIR 31
AMS167		Pile Footing		Vertical Location	Length	> 4.5 m (15')				REPAIR 32

REPAIR 26:	The piles have reached sufficient depth below the assumed scour line. If adequate bearing has been obtained, stop driving at this depth. If only one pile within a footing is driving short, boulders or some other type of obstruction has been hit. In this case, consult with the District Construction Engineer for appropriate solution.
REPAIR 27:	Either an assumed scour line is not available or the piles have not reached sufficient depth below the assumed scour line. In either case, the District Construction Engineer should be consulted for appropriate solution.
REPAIR 28:	A sufficient percentage of the pile has been driven. The recommendation is to stop driving at this depth. However, if only one pile within a footing is driving short, boulders or some other type of obstruction has been hit. In this case, consult the District Construction Engineer for appropriate solution.
REPAIR 29:	A sufficient percentage of the pile has not been driven. The recommendation is to consult with the District Construction Engineer for appropriate solution.
REPAIR 30:	Since the pile is not obtaining adequate capacity and it is a friction pile, the Geologist should be consulted about using the Pile Driving Analyzer (PDA).
REPAIR 31:	There is an absolute minimum length of pile based on structural stability. The pile has not been driven to this depth. Consult the State Bridge Office for appropriate solution.
REPAIR 32:	There is an absolute minimum length of pile based on structural stability. The pile has been driven to this depth. Consult District Construction Engineer if you have other concerns.

Table 8. Pile Footing and Pile Bent Knowledge Representation and Repair Procedures: Vertical Location Problems

3.6 Knowledge Engineering

Knowledge engineering entailed structuring the system knowledge-bases by using an expert system shell. Level5 Object was used to define the needed attributes, attribute types, and final goals; model the knowledge representation and create the decision trees; construct the production rules, "when-needed" and "when-changed" methods, demons, and user interfaces. An iterative development was necessary to achieve the desired performance. This required a series of successive refined prototypes derived from the previous prototypes and modified based on testing with additional example cases and revisions from the domain experts.

3.6.1 Level5 Object Expert System Shell

Level5 Object was used successfully for the previous expert system design project and was therefore the expert system shell used for this project. Specific information on the selection process can be found in (Hess & Roddis 1994; Melhem et al. 19 94). Level5 Object is a rule-based expert system that can interface with other programs as well as call external programs. It includes backward chaining, forward chaining and performs "when-changed" and "when-needed" methods for rule firing. When-changed methods contain a sequence of procedural statements that execute when an attibute's value changes. When-needed methods contain a sequence of procedural statements used when determining an attribute's value. This shell is one of the easiest systems on which to formulate rules with a graphical editor and a windows interface. The program has a debugging feature that allows rule stepping or a complete history of a session to be recorded. Several add-on packages include printing and saving capabilities and a means to include standard windows help files. Figure 14 shows the procedures used in the development and modification of the expert system and the corresponding Level5 Object facility used.

3.6.2 BCX Architecture

The Bridge Construction eXpert system was developed with future expansion in mind. This project completed the pier footing submodule excluding coverage of drilled shafts. The overall architecture of BCX is divided into three main modules, substructure problem solution, superstructure problem solution, and training. The substructure and superstructure modules are divided into submodules that cover a more specific area within the module topic as shown in Figure 15. The training module was designed to cover the entire scope of bridge construction.

3.6.3 Knowledge Representation

Using Level5 Object, the knowledge is represented by class-attribute-value triplets. The relationship between the attributes is represented by rules and demons which form the logic of the expert system. User displays are created to obtain information from the users. In order for the expert system to determine a solution to a given problem, goals for the backward chaining inference engine are outlined in an agenda. The agenda lists attributes in a numbered, hierarchical order for the inference engine to search.

The design of the expert system was separated into problem solution and training. The problem solution submodule contains thirty-three attributes, thirty-five rules, thirty-six

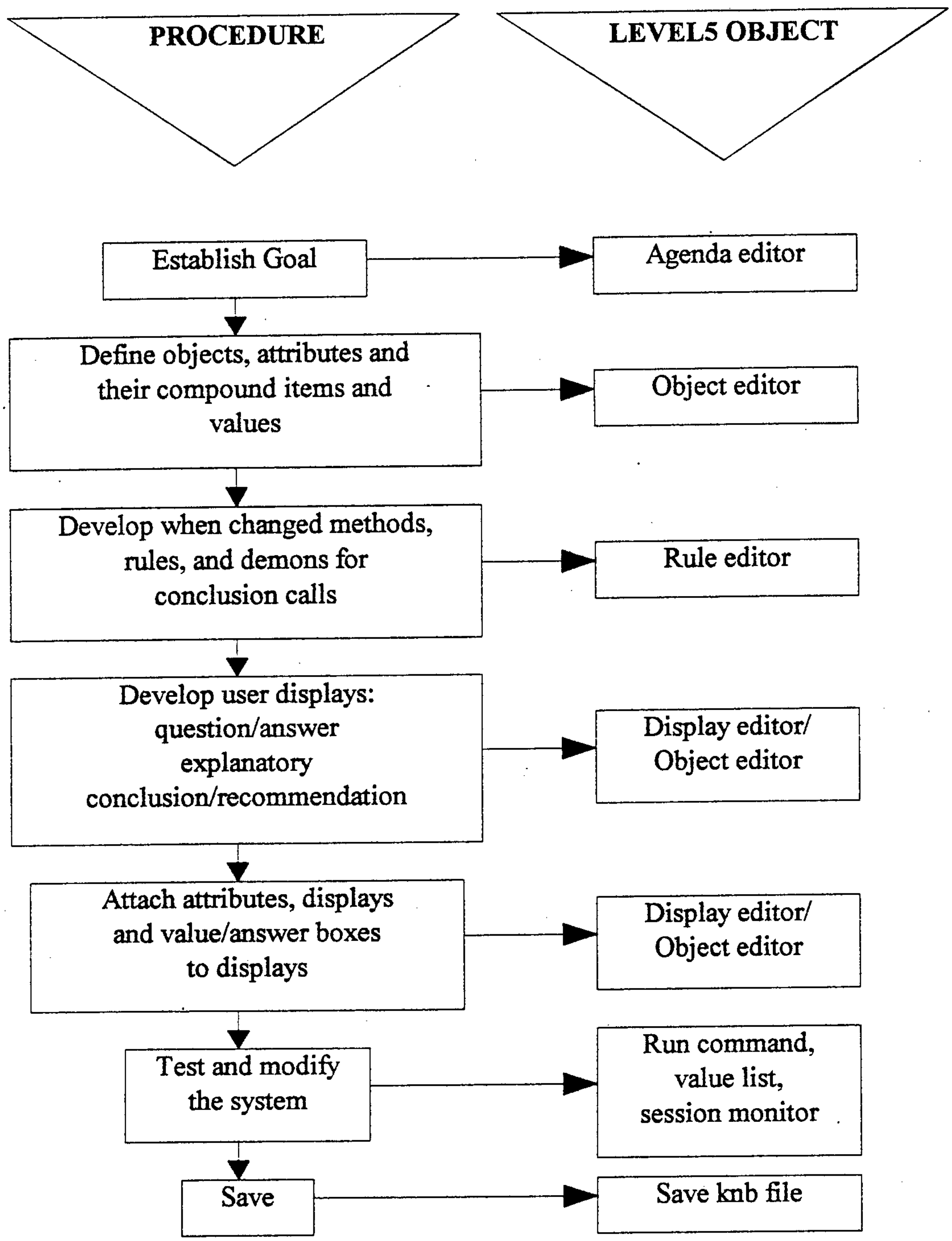

Figure 14. Procedures Used in the Development and Modification of BCX and the Level5 Object Facility Used. (after Kaetzel et al. 1993)

demons, sixteen when-needed methods, and nineteen user interfaces. The training module contains twenty-two attributes, six rules, six demons, eleven when-needed methods, and eighty user interfaces. The text for the training module is contained in Appendix C and the code for the problem solution submodule is contained in Appendix D.

3.6.4 Prototype Development

A preliminary prototype was developed and demonstrated to members of both panels at the knowledge acquisition/preliminary testing and verification meetings (February 19th and 20th). The system was evaluated on functionality and user friendliness. Most of the features of the preliminary prototype were accepted for final development. However, it was suggested to remove some of the descriptive screens to allow the system to run smoother and quicker. In addition, it was suggested to add file saving capabilities so that users in the field on a laptop computer without a printer could obtain a hard copy when they go back to the office or at a later time. The preliminary prototype was refined and modified to represent the final system. This system was tested during the testing and verification meetings discussed in Section 3.7.

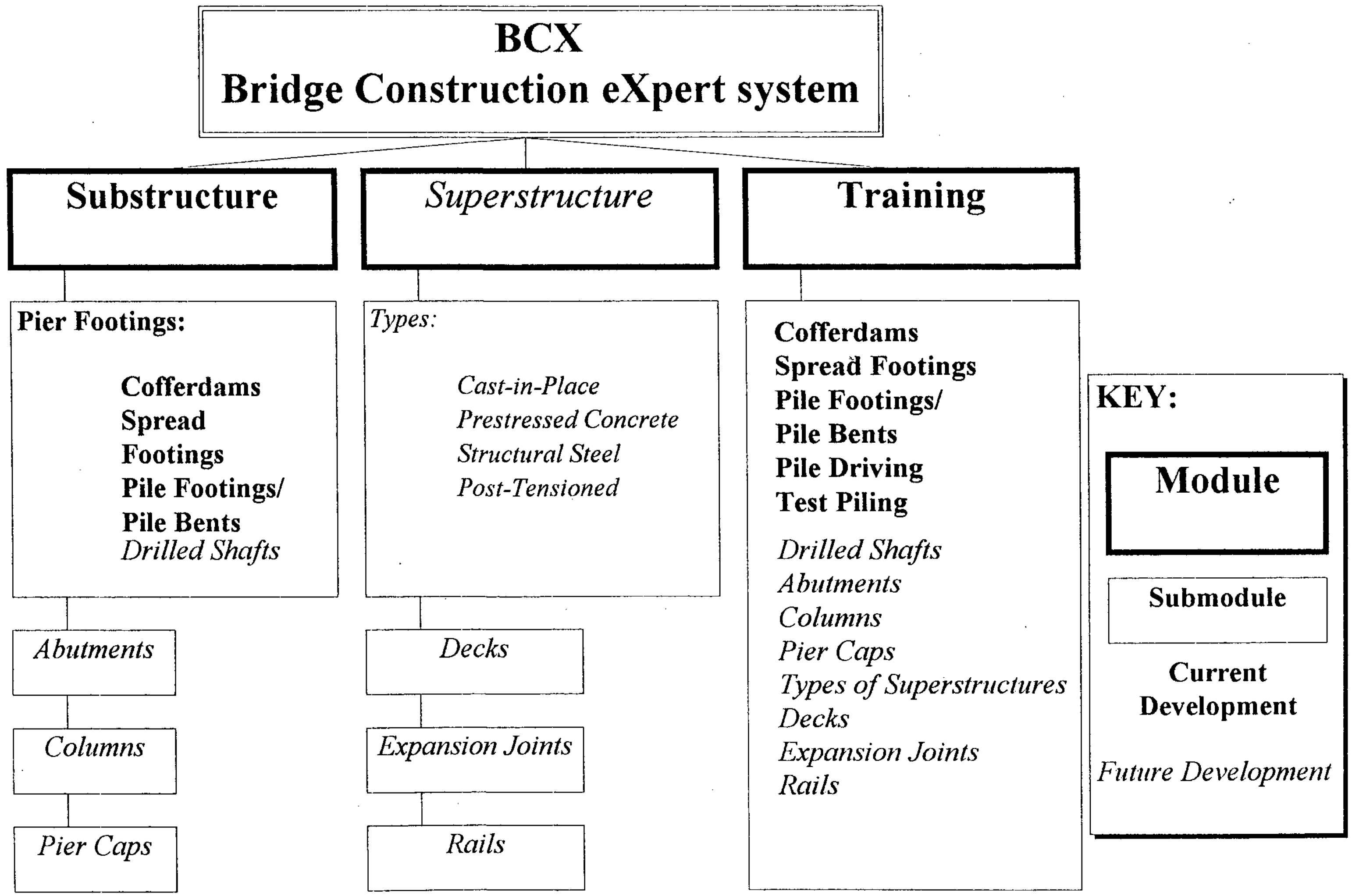

Figure 15. BCX Architecture

3.7 Testing and Verification

The testing and verification phase of the development consisted of meetings that included the research team, the Panel of Experts and the Panel of Users. During these meetings, the system was demonstrated and its performance was discussed and evaluated based on appropriate case studies. Feedback, comments, and corrections were incorporated in the revised versions of the system when appropriate.

The first testing and verification meeting was held on April 23, 1996. Several members of both panels were present. The objectives of this meeting were to demonstrate the final prototype and allow the members present to run example cases and test the results the system was providing and run the training module to determine its effectiveness. One or two members actually sat at a computer and used the system as an expected end user would. The specific results of the test cases run are discussed in Section 4.2 Testing and Verification Results. At least one more testing and verification meeting will be scheduled to include representative end-users.

3.8 Project Evaluation and Documentation

The final phase of the development is to evaluate the overall project and to document the development and results. The overall project evaluation will be completed at the project termination date. At that time, all the documentation will be compiled and presented to KDOT in the final report.

4.0 BCX Performance

The Bridge Construction eXpert system was designed to resemble the Bridge Fabrication eXpert system (BFX) currently in place at KDOT. It starts with the main menu shown in Figure 16. The user has the option to run the substructure or the superstructure module. The user must then determine whether to run a problem or to look at the training information.

The problem solution submodule can be run using a database input file or by user input as prompted by displays. Either method will result in the expert system searching the agenda for the goal or goals to be determined. The inference engine is led by the order of these goals within the agenda. The expert system tries to obtain the information through user input or database input to prove the first goal. If the first goal is disproved, the second goal is tried and the process continues until a goal is proven. The goals of the pier footing expert system are the recommendations for a given problem. As the user inputs data relative to their specific problem or as the database file is read, the premises to the goals are searched in order to determine the final goal of this problem. The objective of this expert system was to recommend no solution rather than an incorrect solution. Therefore, if the user input does not match the premises of any goals, the expert system concludes that either enough information has not been given or the problem given is not covered. The conclusions and recommendations for the given problem are shown to the user in the final display as shown in Figure 17. This screen also allows the user to view a more descriptive picture or drawing, view the input/output report, run a new problem, or quit. When the user views the

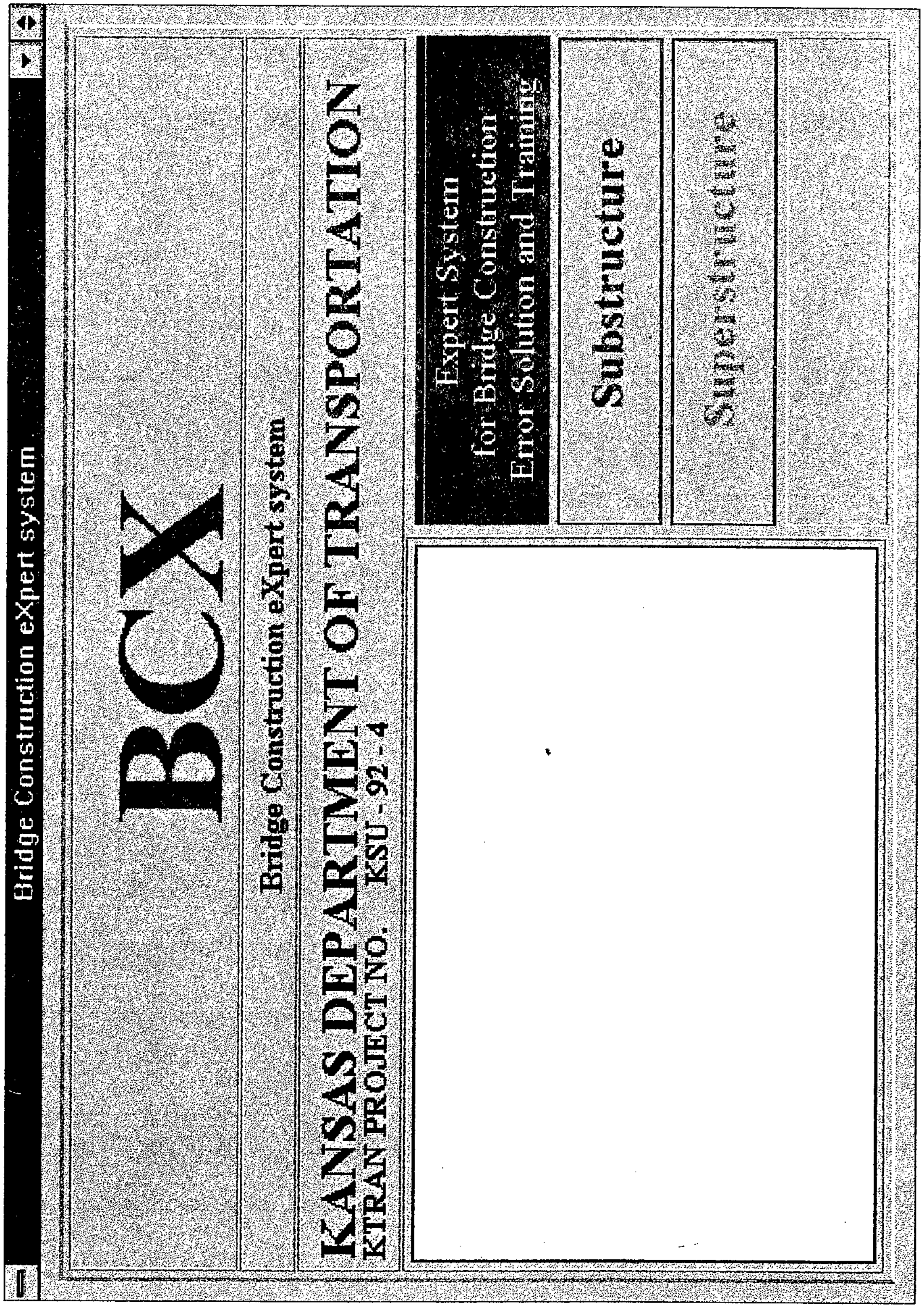

Figure 16. BCX Main Menu

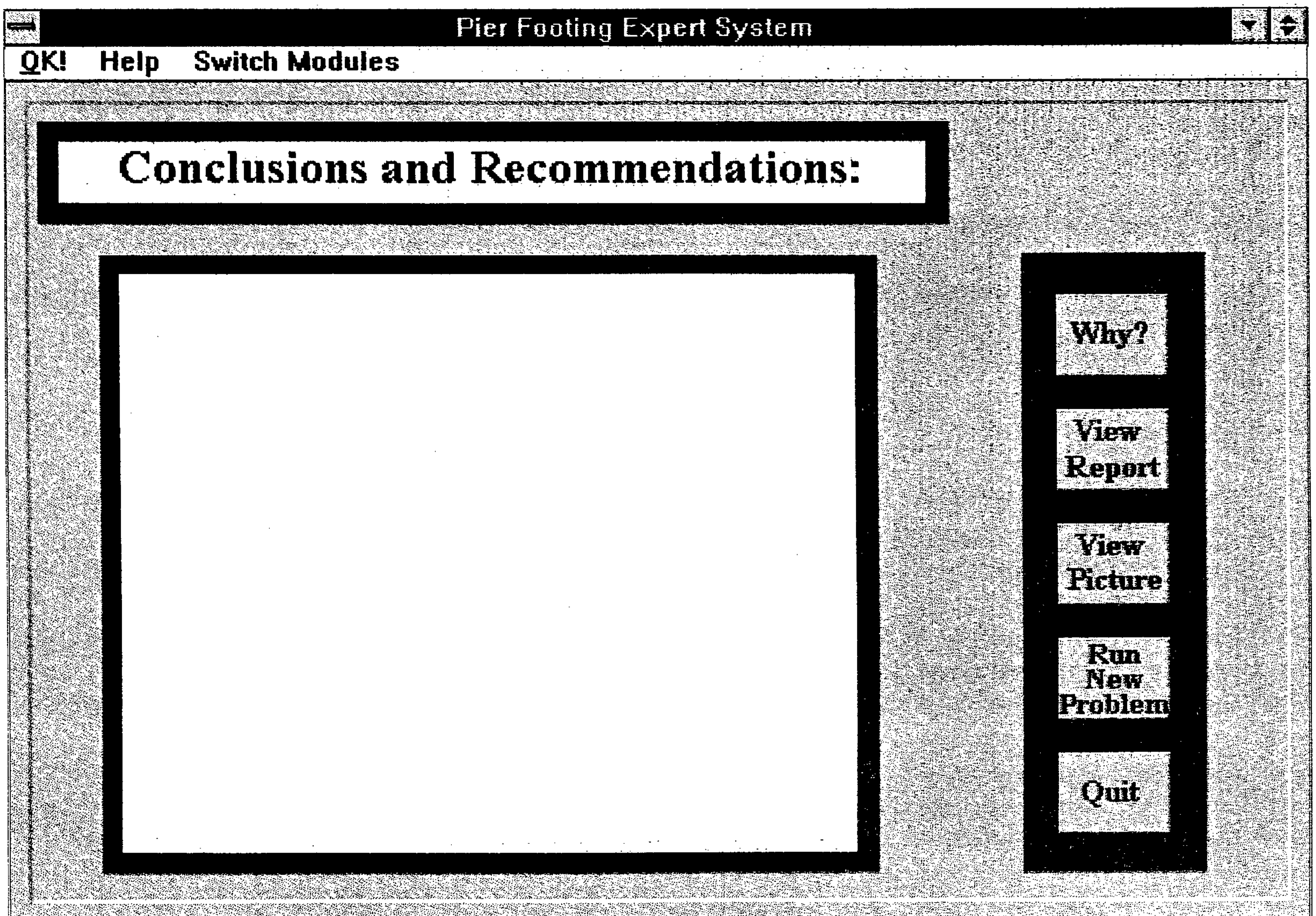

Figure 17. Conclusions and Recommendations Display

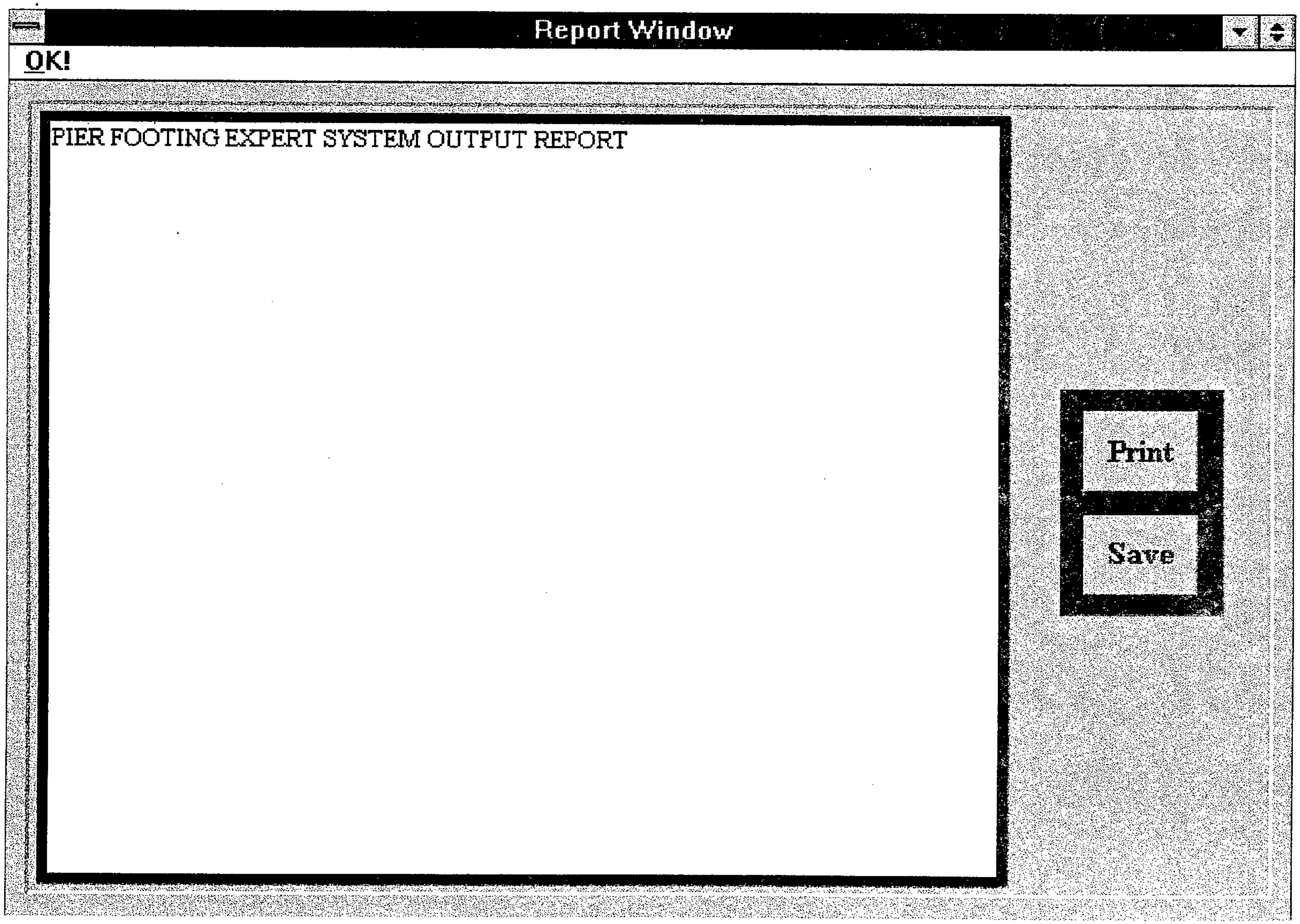

Figure 18. Output Report Display

input/output report, they are given the option to print or save the report as shown in Figure 18. At any time during a run, the user can access help or switch to the training module.

The training module is far less of an actual expert system. It is more of a user interactive training tool. The user has the option to run either a comprehensive tutorial, a specific topic search, or a dictionary. The comprehensive tutorial leads the user through all of the information within the training module. The comprehensive tutorial screen is shown in Figure 19. As the figure shows, the user can page through the information by using the forward and backward buttons on the lower left hand side of the screen. In addition, they can print a topic, view a more descriptive picture or drawing, get help, access the dictionary (currently by selecting help), or switch to the specific topics search. The specific topics search allows the user to select a topic to view and keeps track of what the user has already viewed. The specific topics search screen is shown in Figure 20. By selecting a specific topic to view, the user is placed in the comprehensive tutorial at the position of the topic chosen. As Figure 20 shows, the training module covers pile footings, pile bents, spread footings, and cofferdams. Each topic contains a definition, things to keep in mind, expert's advice, potential problems, and where to go for more information about the topic. In addition, a section entitle what the specifications say was added to cofferdams; excavation and blasting were added to spread footings; and pile driving and test piling were added to supplement pile footings/pile bents. The text for the training module can be found in Appendix B. The dictionary option allows the user to view a standard windows help file that contains all the definitions of terms used within the training module. The dictionary was formatted as a help file so that hypertext could be utilized.

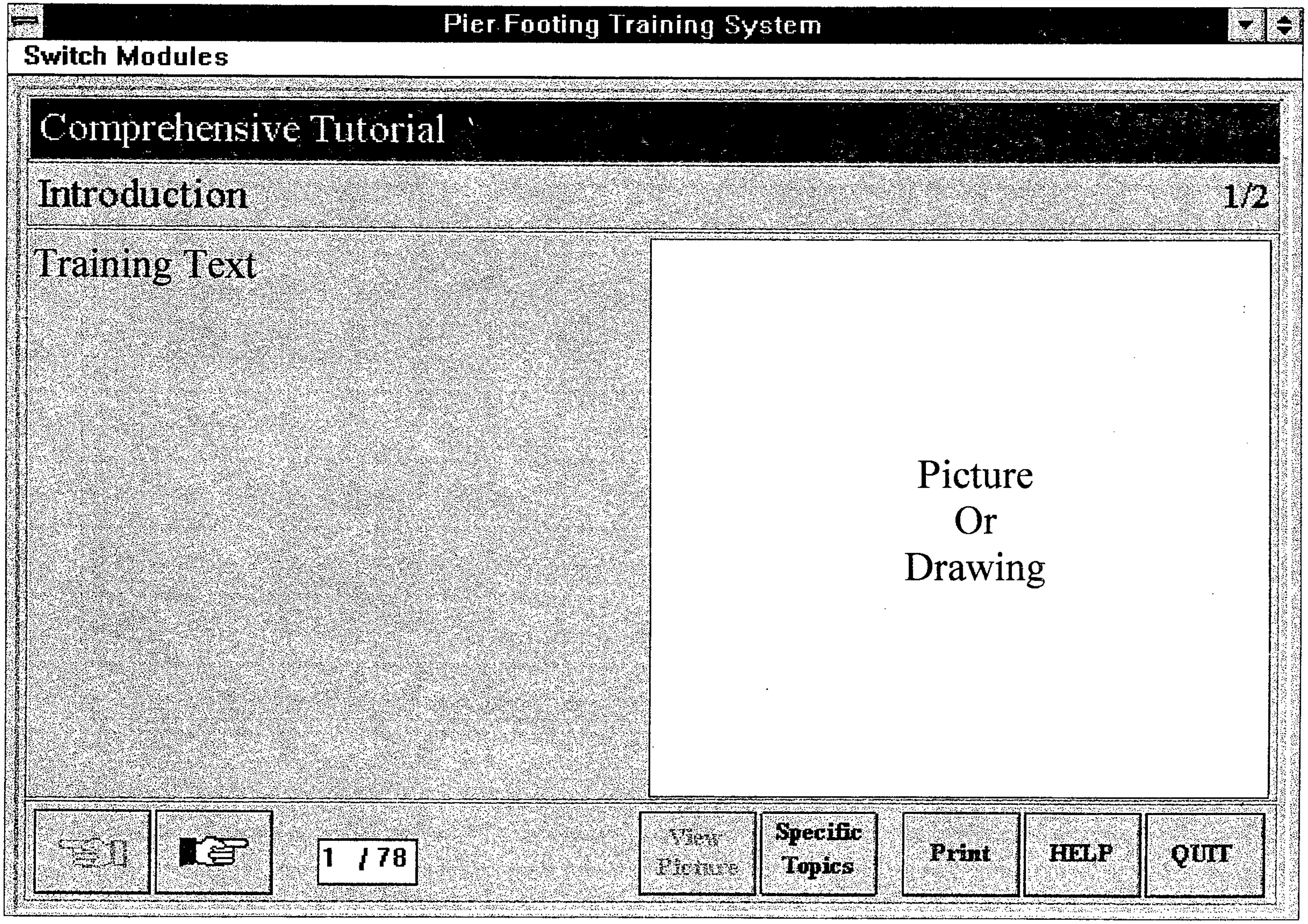

Figure 19. Comprehensive Tutorial Display

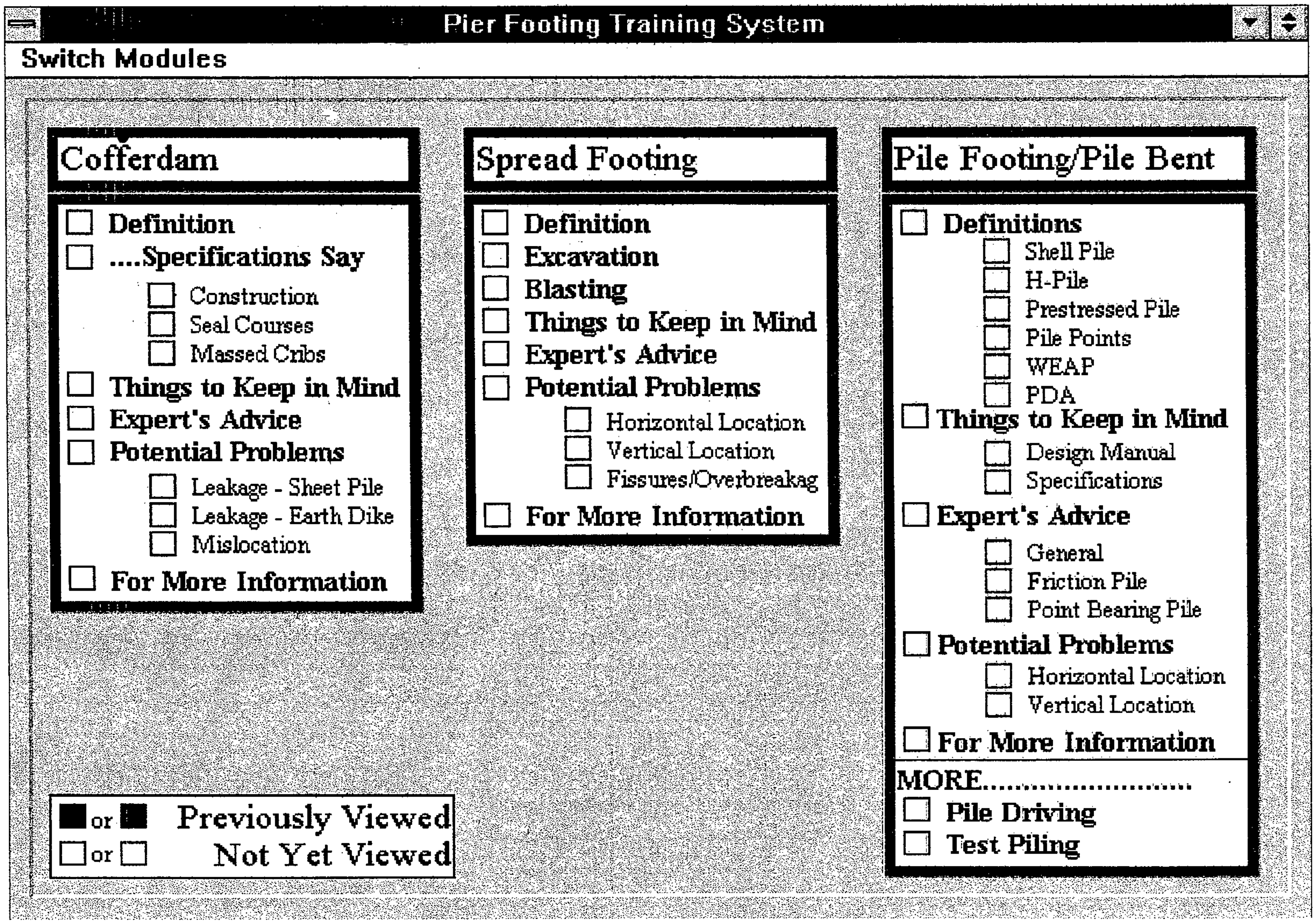

Figure 20. Specific Topics Search Display

4.1 Problem Solution Submodule Example Case

This section walks through an actual construction error example showing how BCX gathers information about the case and then uses the information to match the case with the most suitable repair solution. The problem is with a pile footing construction on an grade separation bridge. The piles were specified on the plans to be driven to a depth of 75 feet. However, in the field the piles reached bearing capacity after only being driven to 65 feet. Therefore, the pile is not obtaining adequate penetration. The Bridge Construction eXpert system is consulted to determine a repair recommendation.

BCX begins with the main menu display as shown previously in Figure 16. The user selects substructure and is then asked whether a problem solution case will be run or whether the training module should be started. The problem solution is selected and the user is now asked a series of questions about the particular problem. The query screens are shown in Figure 21 with the user answers. Query screens are used by BCX to prompt the user for information by presenting several questions on each display screen. This allows the user to answer several questions on each display and decreases the run time per session. The user is not required to answer all the question on each query screen. For example, the user did not have to answer all the questions on the sixth screen. If information that is needed is not answered by the user, BCX prompts the user again for the information. The information obtained from the user is used to match the goals in the agenda. When a match is found, a repair solution is given to the user. If no match is found, the program first asks the user if all the information about the problem has been input. If all the information has been input, the system informs the user that no match was found with the given information. The recommended repair for this problem is shown in Figure 22. By pressing the Why? button, the user can now see the logic used by the system to determine the recommended repair. This is shown in Figure 23. Rule 29 in the agenda matched the input from the user and repair 29 was given. The user can now view the output report and save or print that report, view a descriptive drawing of the repair recommendation if applicable, run a new problem, or quit.

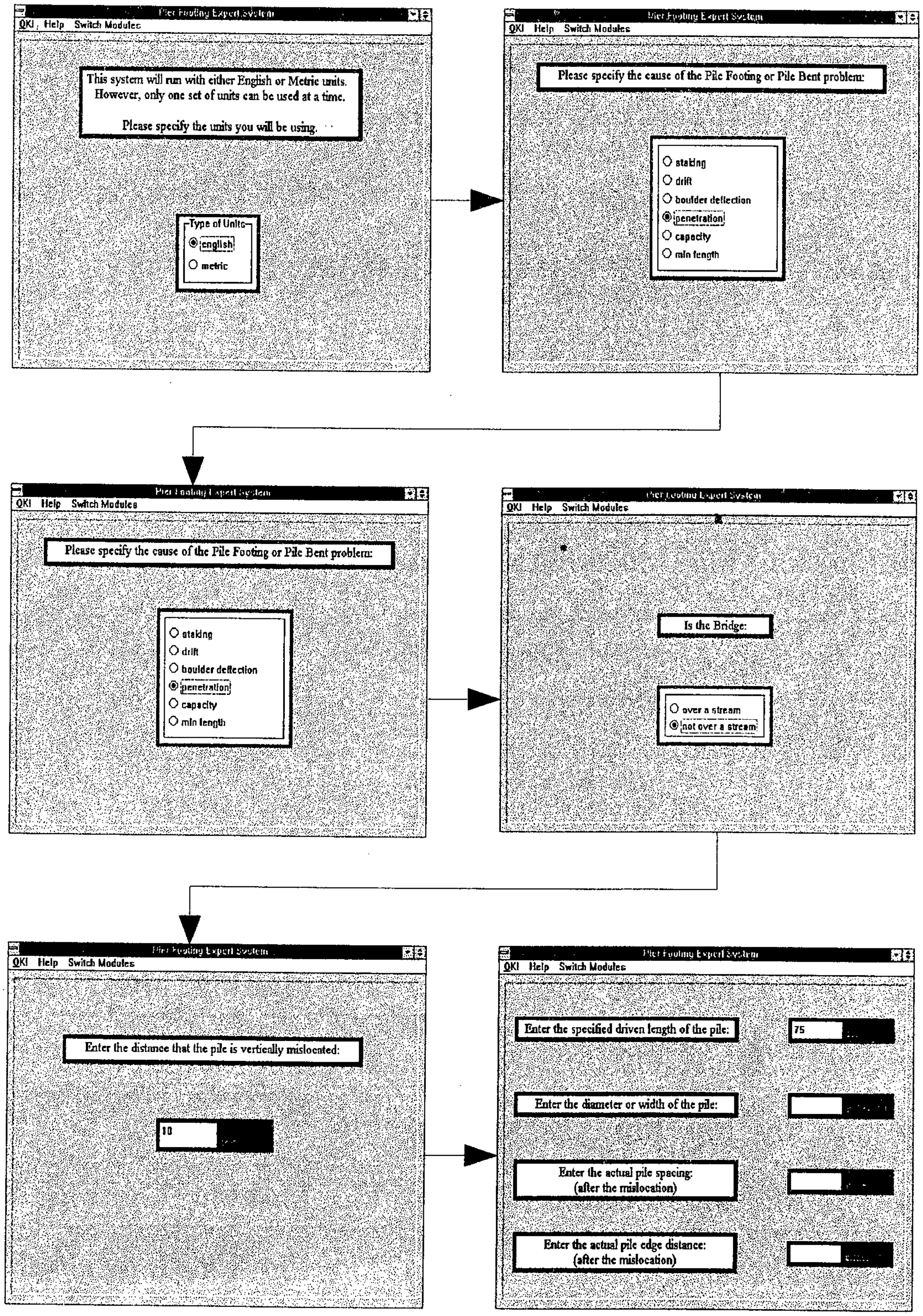

Figure 21. Example Case Query Screens

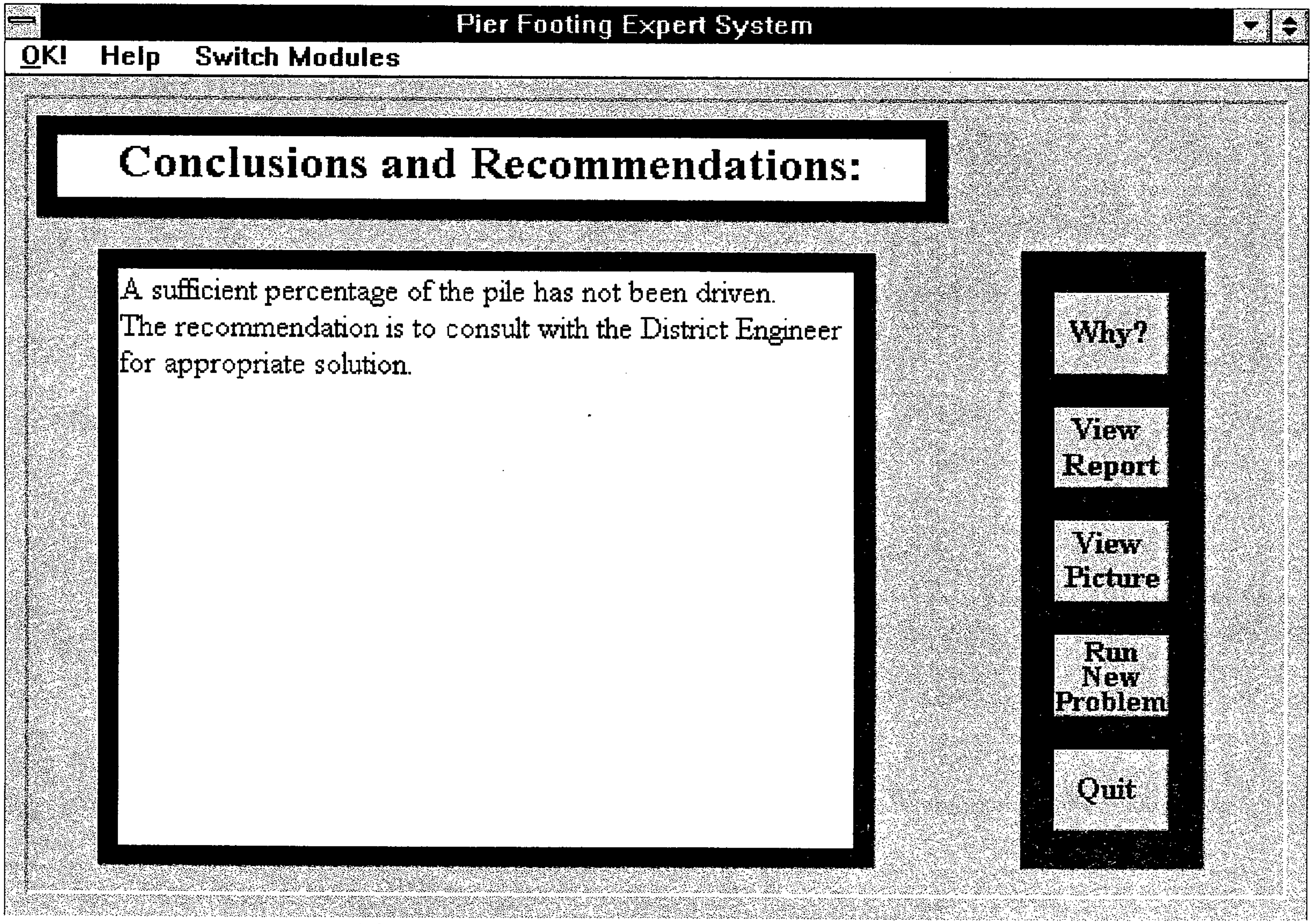

Figure 22. Example Case Repair Recommendation

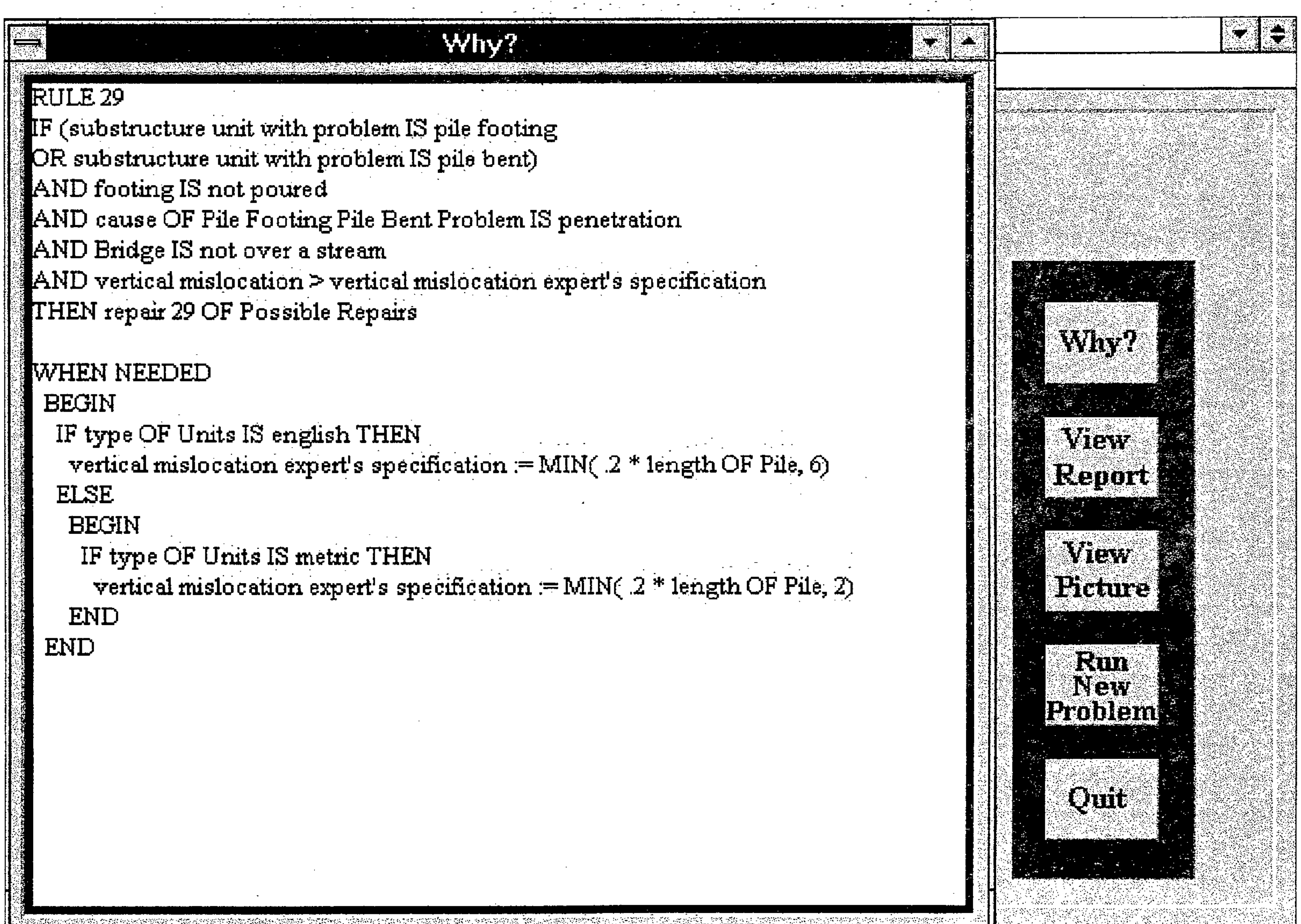

Figure 23. Example Case Reasoning

4.2 Testing and Verification Results

The performance of the final prototype was tested during a testing and verification meeting (April 23, 1996) with several members from both panels as described in Section 3.7 Example cases similar to the one describe in Section 4.1 were run by the members present. These cases were used to validate and verify the knowledge contained within the problem solution submodule. In addition, the panel members evaluated the performance and contents of the training module.

The meeting was divided into two sessions, one in the morning and one in the afternoon. During each session, one or two members sat at a computer and ran test cases on the system. Ninety such cases were run during the two sessions. The results of the test cases are shown in Figure 24. As the figure shows, the repair recommendation was correct 80 percent of the time. Simple logic errors were found within the pile footing and pile bent areas of staking, drift, and boulder deflection. Therefore, the repair recommendation was incorrect 20 percent of the time because of a logic error. However, correcting the logic error results in a correct repair recommendation 100 percent of the time. No test cases were run that resulted in a no match or a incomplete repair. The training module contents were examined by the members for errors and for missing information. It was found correct and complete. However, a number of suggestions were made to improve the wording in several instances. The text of the training module can be found in Appendix B.

Test Date	Number of Cases	Substructure Unit	Specific Error	Repair Recommendation	Comments
4/23/96	6	Spread Footing	Cofferdam Interference	correct	
4/23/96	6	Spread Footing	Incorrect Excavation	correct	
4/23/96	3	Spread Footing	Fissures	correct	
4/23/96	6	Spread Footing	High Bedrock	correct	Remove drill pilot hole question
4/23/96	6	Spread Footing	Low Bedrock	correct	and change bedrock to formation
4/23/96	6	Spread Footing	Unsound Material	correct	
4/23/96	3	Spread Footing	Overbreakage	correct	
4/23/96	3	Pile Footing	Staking	logic error	Combine with drift and boulder deflection
4/23/96	3	Pile Footing	Drift	logic error	Combine with staking and boulder deflection
4/23/96	3	Pile Footing	Boulder Deflection	logic error	Combine with staking and drift
4/23/96	6	Pile Footing	Penetration	correct	
4/23/96	6	Pile Footing	Capacity	correct	
4/23/96	6	Pile Footing	Minimum Length	correct	Add to penetration
4/23/96	3	Pile Bent	Staking	logic error	Combine with drift and boulder deflection
4/23/96	3	Pile Bent	Drift	logic error	Combine with staking and boulder deflection
4/23/96	3	Pile Bent	Boulder Deflection	logic error	Combine with staking and drift
4/23/96	6	Pile Bent	Penetration	correct	
4/23/96	6	Pile Bent	Capacity	correct	
4/23/96	6	Pile Bent	Minimum Length	correct	Add to penetration
Total	90				
Correct	72	Percent Correct	80.0%		
No match	0	Percent No match	0.0%		
Incomplete	0	Percent Incomplete	0.0%		
Logic error	18	Percent Logic error	20.0%		

Figure 24. Validation and Testing Results

VALIDATION AND TESTING
PANEL TESTING SESSION EVALUATION RESULTS

NOTE: Values are averages of panel member responses.

Rate the performance of the program on a scale of 1 to 5.
(1) is Poor (2) is Below Average (3) is Average (4) is Good (5) is Very Good

Screens:
1. Please give your impression of the following screens and give any comments:

Main Menu 4.2

Submodule Menu 4.2

Query 4.0

Conclusions and Recommendations 3.8

Output Report 4.2

Training Text 4.0

Specific Topics 4.2

2. Is the sequence of the query screens well organized? 4.0

Program:

3. Did the performance of the system meet your expectations? 4.0

4. What is your overall confidence in the repair recommendations? 4.0

5. What is your overall impression of the system? 3.9

Figure 25. Panel Testing Session Evaluation Results

After approximately two hours of using the system, the panel members were asked to evaluate the system. The compilation of the evaluations is shown in Figure 25. The members rated the performance of the system on a scale of 1 to 5: (1) is Poor, (2) is Below Average, (3) is Average, (4) is Good, and (5) is Very Good. As shown in Figure 25, the average evaluation of the screens was between 3.8 and 4.2 and the sequence of the query screens was felt to be well organized. The performance of the system was rated as 4.0 based on the members' expectations of how the system would perform. The overall confidence in the repair recommendations was rated as 4.0 after the corrections to the logic errors. Finally, the overall impressions of the system was rated at 3.9.

A final testing and verification meeting will be scheduled on a future date. This meeting will be with the members that were unable to be at the previous meeting. The comments made by the members at the first meeting will be incorporated and the system will be evaluated again.

5.0 Conclusions and Recommendations

The Bridge Construction eXpert system has been developed following a specific methodology tailored to deliver a system that addresses the real needs of the Kansas Department of Transportation. By following a well-established development methodology, the individual tasks of the project were clearly identified and could more easily be completed. The key to the success of this expert system research and past research for KDOT has been the formation of panels of experts and users at the very beginning of the project. By including these individuals in the development process, the expectations of the system are known and can be met. The panel of experts served as the primary source of knowledge and defined the goals of the project. The panel of users serves as a secondary source of knowledge and defined the user interface of the system.

The scope of the system was limited to pier footing construction errors excluding drilled shafts. The scope was established to cover areas where little technical documentation existed. By strictly limiting the scope, the final system completely covers the specified topics rather than briefly covering many topics.

Knowledge for the system was acquired through case histories, expert interviews, and current documentation in the area. It was found that many construction errors are never documented. The error must be fairly severe to be documented. Therefore, the use of case histories for the development was found to be unsuccessful. The majority of the knowledge used for the development was acquired through meetings and interviews with the experts. The rest of the knowledge was obtained from KDOT Standard Specifications, Construction

Manual, and Bridge Design Manual.

The system was designed to resemble the existing expert system BFX. The Panel of Users identified key components of BFX to maintain and additional features to add in the development of BCX. The database interface was an added feature for BFX as well as BCX. This option allows the user to use an existing database record as an input file. In addition, all new cases can be saved to the database. This option provides a method to record all construction errors that occur. In order to ease future expansion, the system was designed in modules and submodules. This format allows the program to be easily maintained and modified as future development occurs or future cases become available.

The testing and verification of the system has thus far been very successful. The repair recommendations for the test cases run during the validation meeting were correct 80 percent of the time. The remaining 20 percent were incorrect because of a simple logic error. Therefore, by correcting the logic error, the system gives the correct repair recommendation 100 percent of the time. The system performance has met the expectations of the panel members as shown by their evaluations of the system.

The development of this project has successfully continued expert system development for the Kansas Department of Transportation. This system can provide better allocation of scarce resources, more consistent quality of solutions, and improved personnel productivity and performance which leads to improved efficiency and reliability at reduced cost. In addition, the development goal has been met by creating a system that will provide not only the most suitable repair solution in a timely manner, but also adequate training in order to prevent future errors from occurring. The benefit to KDOT is that established expert system technologies were utilized to achieve better and less costly construction and erection of highway bridges to meet the needs of the people of Kansas. Particularly, this project provided continuity in the technology transfer of expert system methodology from a research to a practical environment. In addition, the development of this expert system has brought together design engineers, construction engineers, contractors and field inspectors. The meetings, discussions, and interviews have helped these individuals to not only identify, but also resolve the differences between their respective ways of looking at the same problem. As KDOT lacks a construction guide that should address construction errors, this system has helped bridge the gap between the different people that are involved in the various tasks of the same project, and set a unified procedure and practice that they all have been able to agree upon.

Future research should address the continuation of this project to expand the scope to include all of bridge construction errors. This should be accomplished in several short term projects with limited scopes. In this manner, all topics can be completely addressed by the system. In addition, other candidate applications should be explored. Those could include new ideas as well as those generated at the beginning of this project. These projects should also be developed over a short period of time with limited scopes. The established development methodology will allow this future research to meet the mission and needs of the Kansas Department of Transportation.

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Appendix A - Glossary

Agenda A means for organizing goals in an expert system.

Algorithm A set of step-by-step instructions for accomplishing a task.

Antecedent A condition in a rule's premise. (also see premise)

Artificial intelligence A field of study in computer science that pursues the goal of making a computer reason in the same manner as humans.

Attribute A property of an object.

Backward chaining An inference control strategy. In a rule-based system, backward chaining begins with a goal and tries to prove it to be true by proving the premises of a rule that contains the goal as its conclusion. The premises of this rule are considered "subgoals," which the system tries to prove are true by pursing other rules that contain the subgoals as conclusions.

Class A collection of objects that share common properties.

Common sense A general source of knowledge that humans possess on solving real-world problems obtained through experience.

Consequent The conclusion of a rule.

Consistency Property of a system of rules where all deductions are logically consistent.

Declarative knowledge Descriptive or factual knowledge.

Demon A procedure activated by the changing or accessing of a given slot value.

Demon rule A rule that fires whenever its premises match the contents of the working memory. In Level5 Object, demon rules use forward chaining as the control strategy.

Domain The problem area.

Domain expert A person who possesses the skill and knowledge to solve a specific problem in a manner superior to others.

Expert system A computer program designed to model the problem-solving behavior of a human expert.

Explanation Information provided to justify course of reasoning or conclusion.

Fire To activate the conclusion of a rule if the premises are true.

Forward chaining Inference strategy where conclusions are drawn by first looking at the facts or data on the problem. In a rule-based expert system, forward chaining begins by asserting certain facts, seeing what rules can fire based on these assertions, picking a rule to fire, then cycling. This process is continued until a goal is reached or no additional rules can fire.

Frame A knowledge representation method that associates an object with a collection of features. Each feature or attribute is stored in a slot with a corresponding attribute value, or method for acquiring the value.

Goal A hypothesis to prove in an expert system.

Heuristic Knowledge, often expressed as a rule of thumb, that guides the search process.

Hypertext The organization of information in nodes connected by associated links.

Inference engine Processor in an expert system that matches the facts contained in the working memory and the domain knowledge contained in the knowledge base, to draw conclusions about the problem.

Knowledge acquisition The process of acquiring, organizing, and studying knowledge.

Knowledge base Part of an expert system that contains the domain knowledge.

Knowledge engineer A person who acquires the domain knowledge, and builds and tests the expert system

Knowledge representation The method used to encode knowledge in an expert system's knowledge base.

Meta-knowledge Knowledge in an expert system that explains how the system is controlled or reasons. Knowledge about knowledge.

O-A-V Object-attribute-value.

Object A physical or conceptual item that has a collection of related attributes that describe it.

Premise A statement in the IF part of a rule that must be satisfied before the rule's conclusion is accepted. (also see antecendent)

Reasoning The process of working with knowledge, facts and problem-solving methods to draw conclusions or inferences.

Rule A method of representing knowledge consisting of premises and a conclusion.

Rule-based system A computer program that processes problem-specific information contained in the working memory with a set of rules contained in the knowledge base, using an inference engine to infer new information.

Rule of thumb A rule based on good judgment, gained from experience rather than first principles.

Rule set A set of rules that relate to some common concept or function.

Semantic network A method of knowledge representation using a graph made up of nodes and arcs, where the nodes represent objects and the arcs the relationship between the objects.

Shell An expert system development package that has all the facilities for building an expert system minus the domain's knowledge.

User Interface Expert system component that handles communications between the system and its user.

Validation An evaluative activity that ensures that the software functions and contains the features prescribed by its requirements and specifications.

Value A quantity or quality that describes an attribute.

Verification An evaluative activity that ensures that the software interacts properly with the system and performs its specified function.

Working memory That part of an expert system that contains the known facts of a given session with an expert system.

Appendix B - Training Module Text

Titles [1] := "Comprehensive Tutorial"
Subtitles [1] := "Introduction"
Text [1] := "Welcome to the Bridge Construction Training System. This system was developed to help young inspectors and engineers gain knowledge that is typically gained only through experience. The information in this system was obtained from "experts" in the construction field.

The figure to the right defines the features of this screen."

Titles [2] := "Comprehensive Tutorial"
Subtitles [2] := "Introduction"
Text [2] := "The comprehensive tutorial covers the following topics in order:
Cofferdams
Spread Footings
Pile Footings/Pile Bents

In each topic, the following areas may be covered:
Text
What The Specifications Say
Things to Keep in Mind
Expert's Advice
Potential Problems
For More Information"

Titles [3] := "Cofferdams"
Subtitles [3] := "Definition"
Text [3] := "A cofferdam is a substantially water tight enclosure which will permit the construction of the substructure in the dry and without damage to the work. A cofferdam may be constructed with many building materials in many ways. The three most common ways are the earth-dike cofferdam, the steel sheet pile cofferdam and a well-point system.

Earth Dike Cofferdam:
The earth dike cofferdam is commonly used where the depth of the water is fairly shallow and sound earth is available at the bridge site. Assuming the above conditions are present, the earth dike cofferdam is probably the most economical of all the methods, particularly where more than
one unit may be enclosed with a single earth dike.

Steel Sheet Piling Cofferdam:
The steel sheet piling cofferdam is usually constructed around a template made up of large timbers, H-piling or tube piling which serves as bracing when the enclosed area is de-watered. (KDOT Construction Manual Section 4.03.06)"

Titles [4] := "Cofferdams"
Subtitles [4] := "What the Specifications Say"
Text [4] := "Suitable and practically watertight cofferdams shall be used whenever water-bearing strata are encountered above the elevation of the bottom of the excavation. They shall be sufficiently large to give easy access to all parts of the foundation form and shall be of dimensions not less than those for which payment for excavation is made.

Cofferdam Construction:

Cofferdams shall be sunk to a depth well below the bottom of the excavation or to an elevation as near the bottom of the excavation as foundation conditions will permit; shall be substantially braced in all directions, and of such construction as will permit them to be pumped free of water, and kept free until the concrete has been placed. They shall be such that leakage can be kept out of the concrete or masonry area. Unless otherwise shown on the Plans or agreed upon cofferdams and all sheeting or bracing shall be removed after the completion of the concrete or masonry.

(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [5] := "Cofferdams"
Subtitles [5] := "What the Specifications Say"
Text [5] := "Seal Courses:

When the bottom is of sandy or porous material which will not permit the footing to be poured in the dry, it shall be sealed up to the bottom of the footing elevation with the type of concrete specified for the footings so that it may be pumped dry. Other satisfactory methods of sealing out the water may be approved. Under ordinary circumstances the cement content for the seal concrete shall be increased approximately ten percent and the slump of the concrete shall be approximately 150 millimeters (6 inches). A seal course shall not be used unless shown on the Plans or authorized in writing by the Engineer. If the necessity for a seal course is due to inadequate or improper cofferdam construction, the Engineer may order the removal and/or reconstruction of the cofferdam, or permit the placing of a seal course at the Contractor's expense. After the seal course has set, the cofferdam shall be cleared of water and work completed in the dry.

(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [6] := "Cofferdams"
Subtitles [6] := "What the Specifications Say"
Text [6] := "Massed (Weighted) Cribs:

When massed (weighted) cribs are employed and the mass (weight) utilized to partially overcome the hydrostatic pressure acting against the bottom of the foundation seal, special anchorage such as dowels or keys shall be provided to transfer the entire mass (weight) of the crib into the foundation seal.

(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [7] := "Cofferdams"
Subtitles [7] := "Things to Keep in Mind"
Text [7] := "a. The cofferdam is a working tool of the
Contractor. The Contractor is responsible for its design and construction.
b. The cofferdam should be constructed so that it does not seriously hinder navigation or the flow of the river.
c. It's design should be adequate to provide a safe working area.
d. The cofferdam, where required to protect adjacent property or roadways, should be "soil-engineered", and reviewed by the Field Engineer to insure its adequacy and stability with proper wales and bracing.
e. The contractor is required, whenever asked by the Engineer, to submit sketches of the proposed cofferdam for review.

(KDOT Construction Manual Section 4.03.06)"

Titles [8] := "Cofferdams"
Subtitles [8] := "Expert's Advice"
Text [8] := "a. Steel generally doesn't fail suddenly - watch for impending failure.
b. Watch for twisting - the cofferdam may not be properly stiffened.
c. If a P.E. seal was required for cofferdam design, the inspector should make sure that it is constructed accordingly.
d. If the sheets are not deep enough, the water will seep in underneath or the sheet pile could blow in.
e. Permits may be required for construction of the cofferdam."

Titles [9] := "Cofferdams "
Subtitles [9] := "Potential Problems "
Text [9] := "Leakage in Steel Sheet Pile Cofferdam:
A. Cause:
The sheet pile may not be driven deep enough.
Solution:
Check plans for specified depth, splice if necessary

B. Cause:
Seal course may be needed.
Solution:
Seal course should not be used unless shown on the plans or authorized in writing by the Engineer. "

Titles [10] := "Cofferdams "
Subtitles [10] := "Potential Problems "
Text [10] := "Leakage in Steel Sheet Pile Cofferdam:
C. Cause:
Improper placement of seal course
Solution:
Check plans and specifications.(See KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)

D. Cause:
Small gaps in sheet pile joints.
Solution:
Drop fine cinders into the water outside the cofferdam or place hay or straw around the outside at the points of the leakage.

(KDOT Construction Manual Section 4.03.06)"

Titles [11] := "Cofferdams "
Subtitles [11] := "Potential Problems "
Text [11] := "Leakage through or under an Earth Dike Cofferdam:

Solution:
It is a good idea to pump the enclosed area and let the dike stand for a few days before taking drastic action to stop the leaks, because many times the leaks will seal themselves. If leakage of water continues, it can usually be stopped or slowed by the use of well points or by driving steel sheet piling in the badly leaking areas.
(KDOT Construction Manual Section 4.03.06)"

Titles [12] := "Cofferdams "
Subtitles [12] := "Potential Problems "
Text [12] := "Horizontal Mislocation

Causes:
Staking error
Drift

Solutions:
Check plans to see if mislocation will interfere with the placement of the footing.

If interference will cause the footing to be mislocated by less than 300 mm(1 ft):

May be able to pour the footing against the cofferdam.

May be able to shift the footing and reinforcing steel. However, the correct position of the column must be maintained.

If interference will cause the footing to be mislocated by more than 300 mm(1 ft):
Call the District Engineer."

Titles [13] := "Cofferdams"
Subtitles [13] := "For More Information: "
Text [13] := "*KDOT Construction Manual, Section 4.03.06.
*Standard Specifications for State Road and Bridge Construction, KDOT, Section 207.03a."

Titles [14] := "Spread Footing: "
Subtitles [14] := "Definition"
Text [14] := "Footing founded directly on a formation(i.e. shale, limestone). As a KDOT policy, spread footings are not founded on soil.
(Bridge Design Manual, III.D.1.1)."

Titles [15] := "Spread Footing: "
Subtitles [15] := "Excavation:"
Text [15] := "Before the structure excavation has begun, adequate elevations or cross sections of the site must be obtained. This is needed so that the quantity of 'Excavation for Structures' can be accurately determined; however, prior to taking such elevations or sections, the Field Engineer or coordinator should review the plans to determine the limits for the structure excavation. (KDOT Construction Manual, Section 4.03.05)

The foundation pits shall be excavated according to the outlines of the footings as shown on the Plans and shall be of sufficient size to permit the placing of the full widths and lengths of the footings shown with full horizontal beds. Rounded or undercut corners and edges of footings will not be permitted.
(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [16] := "Spread Footing: "
Subtitles [16] := "Excavation:"
Text [16] := "Normally the excavation should be carried to the elevation of the footing shown on the plans. A possible exception would be in the event that a satisfactory foundation in rock can be secured at a higher elevation. It is desirable on a stream crossing that the footing be keyed into the rock or shale. If it appears that the footing elevation can be raised, maintain a keyed depth of 150 mm (6 inches) in rock and 300 mm (1 foot) in shale as a minimum.(KDOT Construction Manual, Section 4.03.05)

Where rock bottom is secured, the excavation shall be done in such a manner as to allow the solid rock to be exposed and prepared in horizontal beds or properly serrated for receiving the concrete. All loose and disintegrated rock and thin strata shall be removed.
(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [17] := "Spread Footing: "
Subtitles [17] := "Blasting:"
Text [17] := "When blasting is necessary in any one pier or abutment after part of the concrete is poured in a column of that pier or abutment, the size of the charge used shall be limited to insure against damage to the previously placed portion of the structure.
(KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03)"

Titles [18] := "Spread Footing: "
Subtitles [18] := "Things to keep in mind:"
Text [18] := "Always compare the material encountered at the footing elevation with that shown on the plans. If the foundation material is not equivalent to that shown on the plans, and thus on which the design was based, it may be necessary to revise the footing elevation, increase the footing size, or redesign the unit. Assistance is readily available from the Bridge or Geology Departments. Do not hesitate to consult the District Construction Engineer for needed assistance. (KDOT Construction Manual, Section 4.03.05)"

Titles [19] := "Spread Footing: "
Subtitles [19] := "Things to Keep in Mind:"
Text [19] := "NOT585 - FOUNDATION ROCK INVESTIGATION: The Contractor, in the presence of the Engineer, shall drill at least one 1.5 to 2 inch diameter probe hole in each footing location to penetrate the bedrock a minimum of 4ft. below the floor of the footing. If a cavity or otherwise incompetent zone is detected in the bedrock below the footing, the footing will be revised to ensure a competent footing.

NOT625 - FOOTING EXCAVATION: When rock or shale is encountered, all excavation below the top of this material or the top of the footing, whichever is lower, shall be to neat lines. No side forming will be permitted below the top of the rock, or shale, or the top of the footing, whichever is lower."

Titles [20] := "Spread Footing: "
Subtitles [20] := "Expert's Advice"
Text [20] := "If the footing is to be placed on shale, pour the footing as soon as possible after excavation is completed. Shale left exposed will deteriorate. "

Titles [21] := "Spread Footing: "
Subtitles [21] := "Potential Problems"
Text [21] := "Horizontal Location:
A. Cause:
Mislocated cofferdam

Solutions:
If interference will cause the footing to be mislocated by less than 300 mm(1 ft):
May be able to pour the footing against the cofferdam.

May be able to shift the footing and reinforcing steel. However, the correct position of the column must be maintained.

If interference will cause the footing to be mislocated by more than 300 mm(1 ft):
Call the District Office."

Titles [22] := "Spread Footing: "
Subtitles [22] := "Potential Problems"
Text [22] := "B. Cause: Mislocated excavation

Solution:
Treat as Overbreakage - place footing in correct location, fill unnecessary excavation with concrete."

Titles [23] := "Spread Footing: "
Subtitles [23] := "Potential Problems"
Text [23] :="Vertical Location
A. Cause:
Encounter bedrock at a higher elevation than anticipated.

Solution:
If bridge is over a stream, the footing elevation was determined based on scour.

Bottom of footing should be placed a minimum of 1.8m (6 ft) below stream bed. (Bridge Design Manual, III.D.4.2).

Could possibly shorten column. However, a shorter column can cause problems if the superstructure needs to move. Be sure to maintain lab lengths.

If bridge is not over a stream, the footing could be raised and the column shortened."

Titles [24] := "Spread Footing: "
Subtitles [24] := "Potential Problems"
Text [24] := "Vertical Location
B. Cause:
Unsound Material/Bedrock at a lower elevation than anticipated.

Solution:
Drill a pilot hole to determine the depth to sound material.

If less than 450 mm(18 inches):
- Excavate to sound material.
- Maintain the footing minimum embedment of 150 mm (6 inches) in rock and 300 mm (1 ft.) in shale(KDOT Construction Manual, Section 4.03.05).
-Thicken the footing.
-Place reinforcing steel mat at the elevation of the plans.

If more than 450 mm(18 inches):
-Call District Construction Engineer."

Titles [25] := "Spread Footing: "
Subtitles [25] := "Potential Problems"
Text [25] := "Vertical Location
C. Cause:
Fissures

Solution:
If fissures are encountered at footing elevations, all loose material shall be removed to a solid condition and the fissures shall be backfilled with concrete.

Overbreakage:
Cut to neat lines, fill with concrete. "

Titles [26] := "Spread Footing: "
Subtitles [26] := "For More Information:"
Text [26] := "*KDOT Construction Manual, Section 4.03.05.
*KDOT Standard Specifications For State Road and Bridge Construction, Section 207.03"

Titles [27] := "Pile Footing/Pile Bent: "
Subtitles [27] := "Definition"
Text [27] := "Footing supported by piles driven to a formation or to a friction bearing value.

Piling is considered when the subsurface conditions are not suitable for spread footings to be used. Since it is KDOT's policy to construct spread footings only on a rock foundation, the use of piling is quite prevalent. Piles are also used as protection against scour.

For a pile foundation to perform satisfactorily, the designer must study and evaluate carefully the properties of the pile materials and the foundation materials around and beneath the piles to determine the proper pile type and length. The Geology Report makes recommendations as to the type and size of pile, pile tip elevation and allowable loads."

Titles [28] := "Pile Footing/Pile Bent: "
Subtitles [28] := "Definition"
Text [28] := "Piles may be classified in two main types, point bearing or friction. Realistically, there is usually friction on any pile and some point bearing at the pile tip. However, a pile that receives the majority of its support from soil near its tip is a point bearing (end bearing) pile, and a pile that receives the majority of its support by friction from the soil along its shaft is referred to as a friction pile.
(Bridge Design Manual, III.D.5)"

Titles [29] := "Pile Footing/Pile Bent: "
Subtitles [29] := "Shell Pile"
Text [29] := "Cast-in-place pipe pile are considered as displacement (friction) type pile. Closed-end pipe piles are formed by welding a watertight plate on the end to close the tip end of the pile. The shell is driven into the foundation material to the required depth and then filled concrete. Thus both concrete and steel share in supporting the load. After the shell is driven and before filling with concrete, the shell is inspected internally its full length to assure that damage has not occurred during the driving operation. Pipe pile may be either spiral or longitudinally welded or seamless steel. Pipe piles are normally used in foundation footings. Their use for aboveground pile bents is not recommended.
(Bridge Design Manual, III.D.5)"

Titles [30] := " Pile Footing/Pile Bent: "
Subtitles [30] := "H-Pile"
Text [30] := "Steel piles are generally used for point bearing piles and commonly utilize the HP-section. H-piles are available in many sizes and lengths and are relatively easy to splice by welding. H-piles are well adapted to deep penetration and close spacing due to their relatively small point area and small volume displacement. They can also be driven into dense soils, coarse gravel and soft rock without damage. In some foundation materials, it may be necessary to provide pile points to avoid damage to the pile.

Exposed steel piles are subject to corrosion and deterioration; however, steel piles embedded in undisturbed material where little free oxygen is present are generally not subject to severe corrosion. Steel near the surface will corrode forming a coating that inhibits further corrosion. Steel piles extending above ground or waterline are subject to corrosion at the contact line due to action of surface water, organic topsoil and oxygen. In this case, piles should be protected by concrete encasement a minimum of 600 mm (2 ft.) below, to about 600 mm (2 ft.) above water or ground line. The piling above this point should be protected as specified for structural steel. In active stream channels, the Engineer should consider the likelihood of stream bed migration when encasing steel piling.

(Bridge Design Manual, III.D.5)"

Titles [31] := "Pile Footing/Pile Bent: "
Subtitles [31] := "Prestressed Pile"
Text [31] := "Pre-cast prestressed concrete piles are used mainly as friction piles, but have occasionally been used as bearing piles. These piling are cast square or octagonal in shape. Prestressing induces compression in the pile which eliminates open cracks and permits sustained bending stresses. It also neutralizes the tensile stresses which can develop under certain driving conditions. The stressing steel is enclosed in a conventional spiral. Lengths are governed by the amount of prestress in the pile and the number of pick-up points. The maximum length of a single prestress pile should not exceed 27 m (90 ft.). Splices are not recommended in prestressed pile because of the difficulty of construction a good joint.

(Bridge Design Manual, III.D.5)"

Titles [32] := "Pile Footing/Pile Bent: "
Subtitles [32] := "Pile Points:"
Text [32] := "Pile points are available for most types of piles. The Geology Report may specify pile points at some sites to obtain a desired penetration or to penetrate existing obstructions in the alluvium. All points should be cast steel. Points are manufactured in various configurations to suit the driving conditions.
(Bridge Design Manual, III.D.5) "

Titles [33] := " Pile Footing/Pile Bent: "
Subtitles [33] := "Wave Equation Analysis (WEAP):"
Text [33] := "With the advent of computers, wave equation programs are having a gradual increase in use for determining the dynamic behavior of piles during driving. The wave equation is based upon the theory of longitudinal wave propagation. The stress wave is generated from the hammer impact on the pile head. The wave equation is useful in determining: (1) pile capacity, (2) driving stresses, and (3) a compatible pile driving system.

The WEAP (Wave Equation Analysis of Piles) program is used to investigate the effects of such factors as ram weight, ram velocity, cushion and pile properties, and the dynamic behavior of the soil-pile interaction during driving. The Wave Equation Model is one in which the driving hammer, hammer cushion, helmet and pile are represented by a series of masses and springs. The soil is represented by a series of elastic-plastic springs and linear dashpots.

(Bridge Design Manual, III.D.5)"

Titles [34] := "Pile Footing/Pile Bent: "
Subtitles [34] := "Wave Equation Analysis (WEAP):"
Text [34] := "One problem with the WEAP program is that assumptions of soil and pile parameters must be made and input into the program. Therefore the predicted pile capacity is only as good as the assumptions made. This problem has been solved by using wave equation analysis in conjunction with field measurements. These measurements are taken by the Pile Driving Analyzer.

(Bridge Design Manual, III.D.5)"

Titles [35] := "Pile Footing/Pile Bent: "
Subtitles [35] := "Pile Driving Analyzer (PDA):"
Text [35] := "The Pile Driving Analyzer can be used in the field to determine the minimum pile length and penetration required, to determine if pile damage has occurred and to determine the efficiency of the driving system.

The Analyzer measures force and acceleration of the pile by attaching strain transducers and accelerometers directly on the pile. For each hammer blow, data is fed into a small field computer and calculations made based upon one-dimensional wave mechanics.

The PDA was developed to perform in a manner that can easily be used on a routine basis in the field. The primary use of the PDA is in driving friction pile. It has limited application for point bearing pile unless a drive history in a particular material is desired or if a cracked or damaged pile is suspected.

(Bridge Design Manual, III.D.5)"

Titles [36] := "Pile Footing/Pile Bent: "
Subtitles [36] := "Pile Driving Analyzer (PDA):"
Text [36] := "The practical results of using the PDA on a specific project are:
a. The pile is driven to a blow count required at a specific site which yields a capacity approximately 2 ½ times the pile design load. (Safety Factor = 2 ½).
b. Provides minimum pile length and penetration required.
c. Indicates if the contractors hammer is adequate to drive the pile and obtain desired capacity.
d. Can measure the actual efficiency of a Contractor's driving system.
e. Can detect if structural pile damage has occurred.
(Bridge Design Manual, III.D.5)"

Titles [37] := "Pile Footing/Pile Bent: "
Subtitles [37] := "Things to keep in mind:"
Text [37] := "Design:

a. The minimum spacing for pile in footings is the greater of 750 mm (2.5 ft.) or 2.5 pile diameters/widths

b. Minimum clear edge distance for piling should not be less than 230 mm (9 inches) to the nearest edge.

c. Piling should be embedded a minimum of 300 mm (1') into the footing.

d. Minimum number of piling in a footing is four.

e. Maximum practical limit of batter is 3 to 12, horizontal to vertical.

(Bridge Design Manual, III.D.4.2)"

Titles [38] := "Pile Footing/Pile Bent: "
Subtitles [38] := "Things to keep in mind:"
Text [38] := "Specifications:

a. Bid Item Test Pile Special - Geologist is to be contacted with Pile Driving Analyzer before any pile are driven.

b. Piles shall be driven within 20 millimeter (1/4 inch) horizontal variation per meter (foot) of length to the vertical or battered lines indicated on the plans, except that foundation piles more than 10.5 meters (35 feet) long or any piles used in bents shall be driven within 10 millimeter (1/8 inch) variation per meter (foot) of length to the vertical or battered line indicated on the plans.

c. The maximum horizontal center-to-center variation on the head of the pile after driving from the position shown on the plans shall be 50 millimeters (2 inches) for piles used in bents and 150 millimeters (6 inches) for foundation piles.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04d)"

Titles [39] := "Pile Footing/Pile Bent: "
Subtitles [39] := "Things to keep in mind:"
Text [39] := "Specifications Continued:

d. All piles pushed up by the driving of adjacent piles or by any other cause shall be redriven at the contractor's cost to required penetration or resistance.

e. Basis of Payment for Cut-offs vs. Splicing:

Steel and Prestressed Concrete Pile Cut-offs = 75 percent of the contract unit price

Cast-in-Place Concrete Pile Cut-offs = 60 percent of the contract unit price.

For each splice of Steel or Concrete(cast-in-place or prestressed) Pile ordered by the engineer and not shown on the plans = 4 times the contract unit price per foot of the type of pile spliced.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.09c)"

Titles [40] := "Pile Footing/Pile Bent: "
Subtitles [40] := "Expert s Advice:"
Text [40] := " a. When problems arise, get back to the original plans as soon as possible.

b. It is good practice to finish driving a complete pile in one day. Overnight you will establish
friction that may result in erroneous values for bearing.

c. The depth of the pile is more important when scour is a concern.

d. If you have penetration and you have reached 100 percent bearing, stop driving.

e. The location of exterior pile, especially the four corner pile, is more critical than the location of
the interior pile.

f. Misaligned piles shall not be forced into proper position after driving is completed. However,
many times piles are held with chains or come alongs during driving in order to retain proper position. This practice should never be used on prestressed pile."

Titles [41] := "Pile Footing/Pile Bent: "
Subtitles [41] := "Expert s Advice:"
Text [41] := "g. There is an absolute minimum length of 4.5 m (15 ft) based on structural stiffness.

h. Pile are theoretically 600 mm (2 ft) long, so 300 - 600 mm (1-2 feet) of cutoff is not uncommon.

I. If 4.5 m-6 m (15' - 20') piles are being driven to a stratum that is known to be impenetrable and of considerable thickness(i.e. limestone), be careful not to overdrive. The piles will drift or bounce on the limestone. It may be necessary to reduce the fall of the hammer.

j. If there is a Test Pile Monitoring Report, it will give more accurate results than the formulas for bearing values in Table 1 of the KDOT Standard Specifications for State Road and Bridge Construction Section 704.03.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04d)"

Titles [42] := "Friction Pile"
Subtitles [42] := "Expert s Advice:"
Text [42] := "FRICTION PILE

a. Driving loads are important
b. The pile can buckle, split, or crack the welds.
c. Important to review the hammer report.
d. If you do not get bearing and are going long- use Pile Driving Analyzer(PDA)."

Titles [43] := "Point Bearing Pile"
Subtitles [43] := "Expert s Advice:"
Text [43] := "POINT-BEARING PILE

a. May have to be predrilled
b. Not only looking for tonnage, but also penetration.
c. Point-bearing pile have more potential to be damage when trying to obtain 1.5 times design
bearing capacity. "

Titles [44] := "Pile Footing/Pile Bent: "
Subtitles [44] := "Potential Problems:"
Text [44] := "Horizontal Location:
A. Causes:
Staking Error.
Drift.

Solutions:
If the center of the pile head is mislocated less than 150 mm (6") or 20 mm / 1 meter (1/4"/1') for pile shorter than 10.5 meters (35') and 10 mm /1 meter (1/8"/1') for pile longer than 10.5 meters (35'), it falls within the specifications. (Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04).

However, edge distance and pile spacing requirements must still be met. The minimum spacing for pile in footings is the greater of 750 mm (2.5') or 2.5 pile diameters/widths. Minimum clear edge distance for piling should not be less than 225 mm (9 inches) to the nearest edge. (Bridge Design Manual, III.D.4.2)."

Titles [45] := "Pile Footing/Pile Bent: "
Subtitles [45] := "Potential Problems:"
Text [45] := "Horizontal Location:
If the mislocated pile creates edge distance or pile spacing problems, the footing design/redesign needs to be checked.

If the center of the pile head is mislocated by more than 150 mm (6") or 20 mm / 1 meter (1/4"/1') for pile shorter than 10.5 meters (35') and 10 mm /1 meter (1/8"/1') for pile longer than 10.5 meters (35'), the footing design/redesign needs to be checked. "

Titles [46] := "Pile Footing/Pile Bent: "
Subtitles [46] := "Potential Problems:"
Text [46] := "Horizontal Location:
B. Cause:
Deflected by boulders.

Solution:
The above solution may be appropriate, however, if boulders have been encountered typically predrilling or jetting is required to obtain design bearing and penetration. The geologist should be consulted."

Titles [47] := "Pile Footing/Pile Bent: "
Subtitles [47] := "Potential Problems:"
Text [47] := "Vertical Location:
A. Cause:
Embedment

Solutions:
If the bridge is over a stream, the pile should be at least 4.5 m - 6 m (15' - 20') below the assumed scour line. If a scour line is not available or the pile cannot be driven to that depth, the design needs to be checked.

If the bridge is not over a stream, pile should be driven to at least 80 percent of the length or within 2 m (6 ft) of plan depth. If pile cannot be driven to that depth, the design needs to be checked.

If only one pile cannot be driven to the specified depth, some type of obstruction has been encountered. The geologist should be contacted."

Titles [48] := "Pile Footing/Pile Bent: "
Subtitles [48] := "Potential Problems:"
Text [48] := "Vertical Location:
B. Cause:
Capacity

Solution:
If the pile is not reaching adequate capacity, the Pile Driving Analyzer should be used.

C. Cause:
Length

Solution:
If the pile cannot be placed with a minimum length of 4.5 meters (15 feet), the pile design needs to be checked."

Titles [49] := "Pile Footing/Pile Bent: "
Subtitles [49] := "For More Information:"
Text [49] := "*KDOT Construction Manual, Section 4.03.08.
*Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30, Section 704."

Titles [50] := "Pile Driving"
Subtitles [50] := "Equipment:"
Text [50] := "The specifications specify what the minimum weight of a gravity hammer must be and the energy rating an air, steam or diesel hammer must have for driving a pile to designated bearing. One purpose of this is to provide sufficient energy for driving the pile to the required bearing without incurring a set or penetration per blow that is so small, that when it is used in the formula for determining the bearing power of the pile, it may give unreliable results.

Each manufacturer of air, steam or diesel type pile driving hammers designate each size of each type of their hammers by a number and the rated energy output of the hammer. This designated energy rating is usually the maximum energy that the hammer is capable of producing as determined by the manufacturer by the use of formulae or by measurement of the energy developed.
(KDOT Construction Manual, Section 4.03.08)"

Titles [51] := "Pile Driving"
Subtitles [51] := "Equipment:"
Text [51] := "The pile hammer data is included as a matter of information for the Inspector and includes the maximum rated energy in joules (foot-pounds), the length of stroke, the mass(weight) of the ram(striking part), the number of blows per minute that the hammer must operate to give the rated energy, and other information relative to the operation of the hammer.

The energy output of a hammer may not, during the driving of a pile, be the same as the rated energy. For a double or differential acting air or steam hammer there should be sufficient air or steam pressure at the hammer to operate the hammer at the number of blows per minute required for a given energy rating. The energy output will vary if the number of blows per minute deviates from the designated number.

For single acting air or steam hammers the energy output is a product of the mass (weight) of the ram and the length of the stroke. It may be assumed that the ram is operating at its full stroke when the required air or steam pressure is maintained at the hammer and the hammer operates
at the designated number of strokes per minute.

(KDOT Construction Manual, Section 4.03.08)"

Titles [52] := "Pile Driving"
Subtitles [52] := "Equipment:"
Text [52] := "Diesel Hammers are of two types. One type has an open upper end whereby the ram is unrestricted in its rebound and is visible above the body of the hammer. The height of the rebound is taken as the length of the stroke for the following blow. Under normal driving conditions, the height of rebound will increase as the resistance of the pile to driving increases. There is a force exerted on the pile by the explosion of the charge of fuel and likewise there is a loss in the kinetic energy developed during the fall of the ram due to the cushioning effect the fuel has on the impact of the ram. It is highly probable that the energy gain of one is about equal to the energy loss of the other, and therefore the energy output for this type of hammer in foot-pounds is the product of the mass (weight) of the ram and the length of stroke.

Measurement of the length of stroke is made by reading the height to which the top of the ram reaches in its rebound on a graduated rod attached to and extending above the hammer body or shell.

(KDOT Construction Manual, Section 4.03.08)"

Titles [53] := "Pile Driving"
Subtitles [53] := "Equipment:"
Text [53] := "For the second type of diesel hammer, the ram operates in a cylinder which is closed at the top and the upstroke of the ram traps and compresses air in the bounce chamber which is the space in the cylinder above the top of the ram. The energy stored in the compressed air is imparted to the ram on the downward stroke. The output energy of the hammer is designated the equivalent energy or equivalent WH since it is made up of the energy produced as a product of the mass (weight) of the ram and this stroke plus the energy stored in the compressed air in the bounce chamber which in turn is equivalent to an additional height in the fall of the hammer.

As the resistance of the pile increases, the force of explosion of the diesel fuel, acting on the ram in its upstroke increases and the increased energy of the ram increases the energy stored in the compressed air chamber which in turn provides an increase in the force imparted to the ram at the start of its downstroke. Thus it is evident that the energy output of the hammer, within the limits of its rated energy output, will increase as the resistance of the pile being driven increases.

(KDOT Construction Manual, Section 4.03.08)"

Titles [54] := "Pile Driving"
Subtitles [54] := "Equipment:"
Text [54] := "Hammers for steel piles, steel sheet piles, and shells for cast-in-place concrete piles:

The mass (weight) of gravity hammers for driving steel piles, steel sheet, and shells for cast-in-place concrete piles shall not be less than 900 kilograms (2000 pounds) and preferably not less than 1600 kilograms (3500 pounds). In no case shall the mass (weight) of the gravity hammer be less than the pile being driven plus the mass (weight) of the driving cap. All gravity hammers shall be equipped with hammer guides to insure concentric impact on the drive head or pile cushion.

The fall shall be so regulated as to avoid injury to the piles and in no case shall exceed 4.5 meters (15 feet). Steam hammers or diesel hammers for driving steel piles, steel sheet piles, and shells for cast-in-place concrete piles shall be of such size that the rated gross energy of the hammer in joules (foot-pound) shall be not less than 2 ½ times the mass (weight) of the pile in kilograms (pounds) and in no case shall the hammer develop less than 8135 joules (6000 foot-pounds) of energy per blow.

Contractor certifications may be used for the mass (weight) of the gravity hammers.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [55] := "Pile Driving"
Subtitles [55] := "Equipment:"
Text [55] := "Hammers for Prestressed Concrete Piles:

Unless otherwise provided, prestressed concrete piles shall be driven with a diesel, steam or air hammer which shall develop an energy per blow at each full stroke of the piston of not less than 1.35 joules (one foot-pound) for each kilogram of mass (pound of weight) driven. In no case
shall the energy developed by the hammer be less than 8135 joules (6000 foot-pounds) per blow.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [56] := "Pile Driving"
Subtitles [56] := "Equipment:"
Text [56] := "Vibratory Hammers:

Vibratory hammers may be used only when specifically allowed by the Contract documents or in writing by the Engineer. Vibratory hammers, if permitted, should preferably be used in combination with pile load testing and retapping with an impact hammer. In addition, one of every ten piles driven with a vibratory hammer shall be retapped with an impact hammer of suitable energy to verify that acceptable load capacity was achieved.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [57] := "Pile Driving"
Subtitles [57] := "Equipment:"
Text [57] := "In case the required penetration and/or bearing is not obtained by use of a hammer complying with the above minimum requirements, the Contractor shall provide a hammer of greater energy and/or when permitted resort to jetting or pre-drilling at his own expense. Use of the pile driving analyzer may be required when minimum requirements are not obtained or results are doubtful.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.31)"

Titles [58] := "Pile Driving"
Subtitles [58] := "Equipment:"
Text [58] := "Hammer Cushion:

All impact pile driving equipment except gravity hammers shall be equipped with a suitable thickness of hammer cushion material to prevent damage to the hammer or pile and to insure uniform driving behavior. Hammer cushions shall be made of durable, manufactured material, which will retain uniform properties during driving. All wood, wire rope, and asbestos hammer cushions are specifically disallowed and shall not be used. A striking plate shall be place on the hammer cushion to insure uniform compression of the cushion material. The hammer cushion shall be inspected in the presence of the Engineer when beginning pile driving at each structure or after each 100 hours of pile driving, whichever is less. The hammer cushion shall be replaced by the Contractor before driving is permitted to continue whenever there is a reduction of hammer cushion thickness exceeding 25 percent of the original thickness.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [59] := "Pile Driving"
Subtitles [59] := "Equipment:"
Text [59] := "The following are acceptable types of hammer cushion material. If the contractor proposes a material type that is not included in this list, then contact the Bureau of Materials and Research.

1. Micarta(Conbest) - This is an electrical insulating material composed of fabric and phenol. It must be replaced when is starts to powderize or when it disintegrates into various layers.
2. Nylon (Blue or other colors) -This material comes in 50 mm (two inch) thick blocks. Occasional vertical cracking is not detrimental. However, after the cushion develops horizontal cracks, it should be replaced.
3. Hamortex - This material consists of metallized paper reels. It has good engineering properties but needs attention as it may compress or disintegrates.
4. Force 10, Forbon, and Fosterlon - These materials are provided by manufacturers of pile driving equipment.
5. Aluminum - Aluminum is often used to separate layers of softer cushioning material. The aluminum does no cushioning itself; however, it is thought to extract the heat from the cushion stack. Once the aluminum is deformed or broken it should be replaced.

NOTE: Wood(plywood or hardwood) will probably remain the most common type of material
used as a pile cushion for gravity hammers.

(KDOT Construction Manual, Section 4.03.08)"

Titles [60] := "Pile Driving"
Subtitles [60] := "Preignition:"
Text [60] := "Preignition means that the fuel combusts before impact occurs. Thus, preignition reduces the ram impact velocity and cushions the impact. When a hammer preignites, the full ram energy is not transmitted to the pile, but rather returned to the ram, causing the stroke to be very high. The low energy in the pile results in a high blow count. Preignition, therefore, has all the symptoms of a hard driving condition at a potentially low soil resistance. Overheated hammers
often preignite after long periods of hard driving when lubrication oil starts to burn or fuel vaporizes prematurely due to heat.

The following are signs of preignition in hard driving:
-Black smoke while strokes are high.
-Flames in exhaust ports.
-Blistering paint(due to excessive heat).
-No obvious metal to metal impact sound.
(KDOT Construction Manual, Section 4.03.08) "

Titles [61] := "Pile Driving"
Subtitles [61] := "Preignition:"
Text [61] := "If preignition is suspected, then the hammer should be stopped, allowed to cool down for an hour, and then restarted. Stroke and blow count should then be accurately monitored. If both stroke and blow counts are lower during the first two minutes after the resumption of driving, then proof exists of a preignition condition before the cooling period was established.

Most atomized fuel injection hammers have some design preignition. The fuel usually starts to burn when the ram is a small distance above the impact block. If the ram descends slowly, the pressure has more time to act on the ram than in the case of a high stroke, when the ram reaches the impact block within a short time. Thus, in hard driving, with high strokes and, therefore, high ram velocities, design preignition is of little consequence. For easy driving, it is often beneficial to keep the hammer running.
(KDOT Construction Manual, Section 4.03.08)"

Titles [62] := "Pile Driving"
Subtitles [62] := "Equipment:"
Text [62] := "Followers:
Followers should not be permitted when driving piling except with permission from the District Construction Engineer. This does not refer to the pile cap which is commonly used to protect and guide the pile in the leads but to the long heavy timber which is sometimes set on top of the pile to facilitate driving at low levels without lowering the pile driver or extending the leads.
(KDOT Construction Manual, Section 4.03.08)"

Titles [63] := "Pile Driving"
Subtitles [63] := "Equipment:"
Text [63] := "Leads:
Pile-driving leads shall be constructed in such a manner to afford freedom of movement of the hammer, and they shall be held in position by guys or stiff braces to insure support to the pile during driving. Except where piles are driven through water, the leads shall be of sufficient length so that the use of a follower will not be necessary.

Inclined leads shall be used in driving battered piles. The driving of piles with followers shall be avoided if practicable and shall be used only with written permission of the engineer. When followers are used, one pile from every group of ten or fraction thereof shall be a long pile driven without followers, and shall be used as a test pile to determine the average bearing power of the group.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [64] := "Pile Driving"
Subtitles [64] := "Equipment:"
Text [64] := "Pile Driving Head:

Piles driven with impact hammers shall be fitted with an adequate driving head to distribute the hammer blow to the pile head. The driving head shall be axially aligned with the hammer and the pile. The driving head shall be guided by the leads and shall not be free-swinging. The driving head shall fit around the pile head in such a manner as to prevent transfer of torsional force during driving while maintaining proper alignment of hammer and pile.

(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [65] := "Pile Driving"
Subtitles [65] := "Equipment:"
Text [65] := "Water jets:

Jetting is to be used only with permission of the Engineer. When jets are used, the number of jets and the volume and pressure of water at the jet nozzle shall be sufficient to erode freely the material adjacent to the pile. The plant shall have sufficient capacity to deliver at all times at least 700 kilopascals (100 pounds per square inch) pressure at 20 millimeter (3/4 inch) jet nozzles. At least 1.5 meters (five feet) before the desired penetration is reached, the jets shall be withdrawn and the piles shall be driven with an approved hammer to secure the final penetration.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 151.30)"

Titles [66] := "Pile Driving"
Subtitles [66] := "Methods - Construction Manual, Section 4.03.08"
Text [66] := "Before starting driving of piling, the excavation shall be complete or in embankment areas the embankment shall be completed to the bottom of substructure concrete elevation. Proper elevation of fill or cut is especially critical in cases where battered piling are involved. On certain wall-type abutments, an error in grade could easily result in the piling being too close to or possibly outside the wall forms. After the contractor completes the actual pile layout, it should be thoroughly checked by the inspector.

After a pile has been placed in position for driving, a check should be made to determine that it is plumb or has the correct batter. Determination should be made during the driving so that the pile is retained in its correct position. Checking the batter of a pile may be made with a spirit level attached to a board which has one edge cut to the required pile batter.

Upon completion of one unit and prior to driving operation in the next unit, it is advisable, whenever possible, to measure the distance between the units to assure that the location of the unit as originally staked is correct."

Titles [67] := "Pile Driving"
Subtitles [67] := "Methods - Construction Manual, Section 4.03.08"
Text [67] := "Leads used for pile driving are either the swing or fixed type. The contractor should be encouraged to use the fixed type wherever possible as they do a better job of holding the pile in position. The batter is checked by making a template to the shape show n on the plans. With a carpenter's level attached to the vertical side of the template, the level should give a vertical indication when the template is held against the pile in its battered position. The vertical piles should be checked regularly during driving to maintain them in as nearly a vertical position as possible. Pile caps conforming to the shape of the top of the pile shall be used in order to prevent damage to the top of the pile. "

Titles [68] := "Pile Driving"
Subtitles [68] := "Methods - Construction Manual, Section 4.03.08"
Text [68] := "When using the gravity hammer, care should be taken to see that there is no undue friction in the drums and no excess kinking or tangling in the cable which will cause an excessive retardation of the fall of the hammer.

When short piling are driven to a stratum which is known to be impenetrable and of considerable thickness, special care should be taken to avoid injury to the piling by overdriving. It may be necessary to reduce the fall of the hammer. It may also be possible to observe during the driving that the penetration is considerably less than that which indicates practical refusal in which case no further test would be necessary, and no further driving of the pile should be attempted. In this case, it is important that all piling be reseated after all piling in the footing are driven as there is a tendency in driving additional piles, to raise those already in place. The Engineer should be satisfied that all piling are driven down to positive contact with the impenetrable stratum before allowing the piles to be cut off."

Titles [69] := "Pile Driving"
Subtitles [69] := "Methods - Construction Manual, Section 4.03.08"
Text [69] := "When making the test blows, there should be little or no bouncing of the hammer. If the hammer bounces to any considerable extent, either the fall is too great, the pile has struck a solid obstacle, or the hammer is too light. When bouncing occurs, careful trials and discriminating judgment are required to determine the cause.
Decreasing the height of fall will sometimes decrease the bouncing and increase the effect of the blow. If the pile has struck an impenetrable stratum or a boulder, and the driving is continued, it is probable that there will be a small and continuous apparent penetration due to the brooming or a failure of the pile. In hard driving, there is likely to be a small rebound of the hammer due to the elastic compression of the pile. The penetration to be used in the formulas should not be taken until it has attained a reasonably uniform or uniformly decreasing rate."

Titles [70] := "Pile Driving"
Subtitles [70] := "Methods - Construction Manual, Section 4.03.08"
Text [70] := "If the piling cannot be driven to the minimum penetration elevation shown on the plans by ordinary driving methods, the Engineer may require the Contractor to operate water or steam jets during driving operations or to use a heavier or larger pile hammer, unless it is very evident that the piling have stopped on an impenetrable stratum.

If the piling are too short to obtain minimum bearing power, the driving of piling should be suspended until it can be determined whether (1) longer piling should be obtained, (2) the piles should be spliced, or (3) the design should be revised by increasing the number of piling or lowering the footing to enable the shorter piling to be used. The District Construction Engineer should be immediately consulted if any of these changes seem necessary. Splices shall be made in accordance with the provisions of the specifications."

Titles [71] := "Pile Driving"
Subtitles [71] := "Methods - Construction Manual, Section 4.03.08"
Text [71] := "Frequent obstructions are encountered which deflect the course of the pile or render it impossible to drive. Driving should be discontinued when it is apparent that the pile is brooming or failing. Piles are damaged and rendered ineffective by continued driving after they have been driven to practical refusal.

Prestressed piles must be driven with steam, air, or diesel hammers. Make sure the rating of the hammer used to drive any piling meets the minimum requirements of the specifications.

The driving of piling, after specified penetration has been obtained, to bearing values that are greatly in excess of plan requirements for the purpose of using up ordered lengths should not be permitted."

Titles [72] := "Pile Driving"
Subtitles [72] := "Methods - Construction Manual, Section 4.03.08"
Text [72] := "The gauge specified for steel shells is the minimum gauge permitted to be furnished. When driving through adverse subsoil conditions, it is the Contractor's responsibility to furnish thicker shells or provide reinforcement of shells to provide the strength and rigidity necessary for driving while remaining substantially watertight.

To the extent practical, all pile driving within a substructure unit should be completed before any concrete is placed in that unit. Should it become necessary to drive piling, or conduct other construction operations that might adversely affect freshly placed concrete, including blasting and demolition of existing structures, within a minimum of 4.5 meters (fifteen feet) from the previously place concrete, such operations should be delayed until the concrete has attained the minimum age of seven days."

Titles [73] := "Pile Footing/Pile Bent: "
Subtitles [73] := "Test Piling:"
Text [73] := "Test piling are driven as an aid in determining the required or ordered length of piling. From a study of the information obtained from the soil borings and the relative location of the proposed substructure units, the number and location of test piles are determined and shown on the plans. Usually one or more test piles are driven at each substructure unit, however, in a small structure, one or two test piles may be all that is required and shown on the plans.
(KDOT Construction Manual, Section 4.03.08)"

Titles [74] := "Pile Footing/Pile Bent: "
Subtitles [74] := "Test Piling:"
Text [74] := "Procedure:
During driving of the test pile, and beginning after the pile has penetrated the upper few feet of any soft or loose soil, measurements are to be taken and recorded to the rate of penetration of the pile at each 500 mm (1 foot) interval for the total depth of penetration. The rate of penetration is the distance in millimeters (inches) that the pile penetrates the soil per blow of the hammer, and it is equal to 500 (twelve) divided by the blows per 500 mm (foot). In the case of test pile, it shall be determined by counting the number of blows of the hammer for each 500 mm (foot) interval of penetration of the pile and computing the rate as the average for the 500 mm (foot) interval.

When driving a test pile, if 500 mm (one-foot) intervals are first marked on the pile and the 1.5 or 3 m (five or ten foot) intervals designated, count of blows per foot may be made as the 500 mm (foot) interval passes a fixed object and determination of the depth of penetration may be made by observing the 500 mm (foot) mark at the ground level.
(KDOT Construction Manual, Section 4.03.08)"

Titles [75] := "Pile Footing/Pile Bent: "
Subtitles [75] := "Test Pile (Special):"
Text [75] := "When the item Test Pile (Special) is shown on the Plans and Contract, the Pile Driving Analyzer (PDA) will be used on the project to monitor the driving of the test pile(s) to the required driving resistance to obtain the desired ultimate loads by preliminary calculations with the Wave Equation Analysis Program (WEAP) and subsequent dynamic measurements the with PDA, following the procedures below.

Once the Contractor's system has been approved no variations in the driving system will be permitted without the Engineer's written approval. Any change in the driving system will only be considered after the Contractor has submitted the necessary information for a revised wave equation analysis.

The Contractor shall provide the Engineer with the pile driving equipment information required from the 'Pile and Driving Equipment Data Sheet' located in the Contract. The Field Engineer will forward this information to the Bridge Engineer to be used in wave equation analysis of pile driving.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04)"

Titles [76] := "Pile Footing/Pile Bent: "
Subtitles [76] := "Test Pile Scheduling:"
Text [76] := "This information will be provided to the Field Engineer at least 14 days prior to the preconstruction conference. The Contractor will be notified of the hammer data analysis results at the Preconstruction Conference.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04)"

Titles [77] := "Pile Footing/Pile Bent: "
Subtitles [77] := "Test Pile Results:"
Text [77] := "The pile driving equipment shall be capable of providing the minimum energy as noted on the Plans. If the analysis shows that pile damage or inability to drive the pile to the desired ultimate capacity will result from the Contractor's proposed equipment or methods, the Contractor shall have two options: (1) Modify the proposed methods and/or equipment, or (2) Provide additional pile cross-sectional area or alternate piling.

Subsequent analysis of the option chosen will be made by the Engineer until the results indicate that the piles can be driven to the desired ultimate capacity without damage.

These options will be provided at no increase in the contract cost.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04)"

Titles [78] := "Pile Footing/Pile Bent: "
Subtitles [78] := "Test Pile - PDA:"
Text [78] := "Dynamic measurements will be taken by the Engineer in charge during driving of a predetermined number of test pile as shown on the Plans. It is estimated that the Engineer will need approximately 1 1/2 hours to prepare the test piling and to install the dynamic measuring equipment. The Contractor shall provide the Engineer safe and reasonable means of access to the pile for preparation and attaching instruments after the pile is placed in the leads. Pile shall be driven in a designated footing to the required driving resistance to obtain the estimated ultimate loads. if non-axial driving is indicated by dynamic test equipment measurements, the Contractor shall immediately realign the driving system. A specified number of test pile may be retapped a minimum of 24 hours after initial driving. The retap will consist of a minimum pile penetration of 150 millimeters (6 inches) or 50 blows, whichever occurs first.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04)"

Titles [79] := "Pile Footing/Pile Bent: "
Subtitles [79] := "Test Pile - PDA Scheduling & Results:"
Text [79] := "The Contractor will notify the Engineer in charge five working days prior to driving test piling on which dynamic testing is required to allow the Department time to mobilize and get test equipment to the field.

The Engineer will utilize the pile driving analyzer results to provide the Contractor with a blow count for production driving.
(Standard Specifications for State Road and Bridge Construction, KDOT, Section 704.04)"

Appendix C - Pier Footing Problem Solution Code

```
$VERSION35
$LOCATIONS ARE PIXELS

CLASS Pile
 WITH type COMPOUND
  H,
  prestressed,
  shell
 WITH resistance COMPOUND
  point bearing,
  friction
  QUERY FROM Pile Resistance Display
 WITH edge distance NUMERIC
  QUERY FROM Pile Details Display
 WITH diameter_width NUMERIC
  QUERY FROM Pile Details Display
 WITH spacing NUMERIC
  QUERY FROM Pile Details Display
 WITH length NUMERIC
  QUERY FROM Pile Details Display
 WITH depth below scour line NUMERIC

CLASS Pile Footing Pile Bent Problem
 WITH cause COMPOUND
  staking,
  drift,
  boulder deflection,
  penetration,
  capacity,
  min length
  QUERY FROM Pile Footing Pile Bent Problem Display

CLASS Possible Repairs
 WITH repair 0 SIMPLE
 WITH repair 1 SIMPLE
 WITH repair 2 SIMPLE
 WITH repair 3 SIMPLE
 WITH repair 4 SIMPLE
 WITH repair 5 SIMPLE
 WITH repair 6 SIMPLE
 WITH repair 7 SIMPLE
 WITH repair 8 SIMPLE
 WITH repair 9 SIMPLE
 WITH repair 10 SIMPLE
 WITH repair 11 SIMPLE
 WITH repair 12 SIMPLE
 WITH repair 13 SIMPLE
 WITH repair 14 SIMPLE
 WITH repair 15 SIMPLE
 WITH repair 16 SIMPLE
 WITH repair 17 SIMPLE
 WITH repair 18 SIMPLE
 WITH repair 19 SIMPLE
 WITH repair 20 SIMPLE
 WITH repair 21 SIMPLE
 WITH repair 22 SIMPLE
 WITH repair 23 SIMPLE
 WITH repair 24 SIMPLE
 WITH repair 25 SIMPLE
 WITH repair 26 SIMPLE
 WITH repair 27 SIMPLE
 WITH repair 28 SIMPLE
 WITH repair 29 SIMPLE
 WITH repair 30 SIMPLE
 WITH repair 31 SIMPLE
 WITH repair 32 SIMPLE
 WITH repair 33 SIMPLE
 WITH repair 100 SIMPLE

CLASS Spread Footing Problem
 WITH cause COMPOUND
  interference with cofferdam,
  incorrect excavation,
  fissures,
  high bedrock,
  low bedrock,
  overbreakage,
  unsound material
  QUERY FROM Spread Footing Problem Display

CLASS Units
 WITH type COMPOUND
  english,
  metric
  QUERY FROM Units Query

ATTRIBUTE Cofferdam used SIMPLE
 SEARCH ORDER CONTEXT WHEN NEEDED RULES QUERY DEFAULT

ATTRIBUTE substructure unit with problem COMPOUND
 spread footing,
 pile footing,
 pile bent
 QUERY FROM Substructure details
ATTRIBUTE horizontal mislocation NUMERIC
 QUERY FROM Horizontal Mislocation Display
ATTRIBUTE vertical mislocation NUMERIC
 QUERY FROM Vertical Mislocation Display
ATTRIBUTE depth to sound material NUMERIC
 QUERY FROM Probe Hole Display
ATTRIBUTE recommendation STRING
 ARRAY SIZE 100
ATTRIBUTE Bridge COMPOUND
 over a stream,
 not over a stream
 QUERY FROM Bridge Details Display
ATTRIBUTE horizontal mislocation specification 1 NUMERIC
 WHEN NEEDED
  BEGIN
   IF substructure unit with problem IS pile footing AND type OF Unit\
s IS english AND length OF Pile <= 35 THEN
    horizontal mislocation specification 1 := .25
   ELSE
    BEGIN
     IF substructure unit with problem IS pile footing AND type OF \
Units IS english AND length OF Pile > 35 THEN
      horizontal mislocation specification 1 := .125
     ELSE
      BEGIN
       IF substructure unit with problem IS pile footing AND type\
 OF Units IS metric AND length OF Pile <= 10.5 THEN
        horizontal mislocation specification 1 := 20
       ELSE
        BEGIN
         IF substructure unit with problem IS pile footing AND \
type OF Units IS metric AND length OF Pile > 10.5 THEN
          horizontal mislocation specification 1 := 10
         ELSE
          BEGIN
           IF substructure unit with problem IS pile bent AND\
 type OF Units IS english THEN
            horizontal mislocation specification 1 := .125
           ELSE
            BEGIN
             IF substructure unit with problem IS pile bent\
 AND type OF Units IS metric THEN
              horizontal mislocation specification 1 := 10
            END
          END
        END
      END
    END
  END
 SEARCH ORDER WHEN NEEDED
ATTRIBUTE horizontal mislocation specification 2 NUMERIC
 WHEN NEEDED
  BEGIN
   IF substructure unit with problem IS pile footing AND type OF Unit\
s IS english THEN
    horizontal mislocation specification 2 := 6
   ELSE
    BEGIN
     IF substructure unit with problem IS pile footing AND type OF \
Units IS metric THEN
      horizontal mislocation specification 2 := 150
     ELSE
      BEGIN
       IF substructure unit with problem IS pile bent AND type OF\
 Units IS english THEN
        horizontal mislocation specification 2 := 2
       ELSE
        BEGIN
         IF substructure unit with problem IS pile bent AND typ\
e OF Units IS metric THEN
          horizontal mislocation specification 2 := 50
        END
      END
    END
  END
 SEARCH ORDER WHEN NEEDED
ATTRIBUTE spacing specification NUMERIC
 WHEN NEEDED
  BEGIN
   IF type OF Units IS english THEN
    spacing specification := MIN( 30, (2.5 * diameter_width OF Pile)\
)
   ELSE
    BEGIN
```

```
      IF type OF Units IS metric THEN
       spacing specification := MIN( 750, (2.5 * diameter_width OF \
Pile))
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE edge distance specification NUMERIC
  WHEN NEEDED
   BEGIN
    IF type OF Units IS english THEN
     edge distance specification := 9
    ELSE
     BEGIN
      IF type OF Units IS metric THEN
       edge distance specification := 230
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE horizontal mislocation specification NUMERIC
  WHEN NEEDED
   BEGIN
    horizontal mislocation specification := MIN( horizontal mislocatio\
n specification 1, horizontal mislocation specification 2)
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE horizontal mislocation expert's specification NUMERIC
  WHEN NEEDED
   BEGIN
    IF type OF Units IS english THEN
     horizontal mislocation expert's specification := 12
    ELSE
     BEGIN
      IF type OF Units IS metric THEN
       horizontal mislocation expert's specification := 300
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE depth to sound material expert's specification NUMERIC
  WHEN NEEDED
   BEGIN
    IF type OF Units IS english THEN
     depth to sound material expert's specification := 18
    ELSE
     BEGIN
      IF type OF Units IS metric THEN
       depth to sound material expert's specification := 450
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE Scour Line COMPOUND
  available,
  not available
  QUERY FROM Stream Details Display
ATTRIBUTE Probe Hole COMPOUND
  drilled,
  not drilled
  QUERY FROM Probe Hole Display
ATTRIBUTE depth below scour line expert's specification NUMERIC
  WHEN NEEDED
   BEGIN
    IF type OF Units IS english THEN
     depth below scour line expert's specification := 17
    ELSE
     BEGIN
      IF type OF Units IS metric THEN
       depth below scour line expert's specification := 5
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE depth below scour line NUMERIC
  QUERY FROM Stream Details Display
ATTRIBUTE vertical mislocation expert's specification NUMERIC
  WHEN NEEDED
   BEGIN
    IF type OF Units IS english THEN
     vertical mislocation expert's specification := MIN( .2 * length \
OF Pile, 6)
    ELSE
     BEGIN
      IF type OF Units IS metric THEN
       vertical mislocation expert's specification := MIN( .2 * len\
gth OF Pile, 2)
     END
   END
  SEARCH ORDER WHEN NEEDED
ATTRIBUTE minimum length expert's specification NUMERIC
ATTRIBUTE restart SIMPLE
ATTRIBUTE footing COMPOUND
  not poured,
  poured
  QUERY FROM Substructure details
ATTRIBUTE New Problem Button SIMPLE
  WHEN CHANGED
   BEGIN
    CHAIN "foundatn.knb"
   END
ATTRIBUTE Next Button SIMPLE
ATTRIBUTE Print Button SIMPLE
  WHEN CHANGED
   BEGIN
    filename OF prinfile 1 := filename OF report
    print OF prinfile 1 := TRUE
   END
ATTRIBUTE All Information Given SIMPLE
  QUERY FROM All Info Given
ATTRIBUTE time TIME
ATTRIBUTE View Report Button SIMPLE
  WHEN CHANGED
   BEGIN
    output OF Report Window := Output Report
   END
ATTRIBUTE Why STRING
  ARRAY SIZE 100
ATTRIBUTE Why? Button SIMPLE
  WHEN CHANGED
   BEGIN
    visible OF Why? Window := TRUE
    output OF Why? Window := Why? Display
   END
ATTRIBUTE Input File Button SIMPLE
ATTRIBUTE Screen Input Button SIMPLE
ATTRIBUTE Save Button SIMPLE
  WHEN CHANGED
   BEGIN
    IF filename OF save output report = "REPORT.TXT" THEN
     ASK report file warning
    ELSE
     BEGIN
      filename OF save file := filename OF save output report
      action OF save file IS open new := TRUE
      action OF report IS open old := TRUE
      DO
       BEGIN
        read line OF report := TRUE
        write line OF save file := current line OF report
       END
      UNTIL (eof OF report = TRUE)
      action OF report IS close := TRUE
      action OF save file IS close := TRUE
     END
   END
ATTRIBUTE Quit Button SIMPLE
  WHEN CHANGED
   BEGIN
    exit OF application := TRUE
   END
ATTRIBUTE Goto Training SIMPLE
  WHEN CHANGED
   BEGIN
    CHAIN "training.knb"
   END
```

INSTANCE the domain ISA domain
 WITH recommendation [1] := "The spread footing problem was caused by \
a mislocated cofferdam.

The footing may be poured against the cofferdam if needed. However, with\
 waler rings inside the cofferdam, you may create additional problems.

Another possible solution is to shift the footing and the reinforcing st\
eel for the footing. However, the position of the column and thus the co\
lumn steel should be maintained.

Consult District Engineer for other solutions."
 WITH recommendation [2] := "The spread footing problem was caused by \
a mislocated cofferdam. The mislocation is too large to recommend a sol\
ution to the problem.

Call the District Engineer for appropriate procedure."
 WITH recommendation [3] := "The spread footing problem was caused by \
an incorrect excavation or overbreakage.

Excavate so that the footing can be placed in the correct location. Cut\
 the excess excavation to neat lines and backfill with concrete.

Consult District Engineer for other solutions."
 WITH recommendation [4] := "The spread footing problem was caused by \
fissures.

Remove all loose material to a solid conditions and backfill with concre\
te. "
 WITH recommendation [5] := "The spread footing problem was caused by \
the bedrock being encountered at a higher elevation than anticipated.

Because the bridge is over a stream, the bottom of the footing should be\
 a minimum of 2 meters(6 feet) below the stream bed.

If this depth has been reached, one possible solution is to shorten the \
column. However, such changes to the substructure design should not be \
made without consulting the Bridge office.

First consult the District Engineer for appropriate solution."
 WITH recommendation [6] := "The spread footing problem was caused by \
the bedrock being encountered at a higher elevation than anticipated.

Because the bridge is not over a stream, the depth of the footing is not\
 as critical because scour is not a concern.

One possible solution is to place the footing at this elevation and shor\
ten the column. However, such changes to the substructure design should\
 not be made without consulting the Bridge office.

First consult the District Engineer for appropriate solution."
 WITH recommendation [7] := "The spread footing problem was caused by \
unsound material or the bedrock not being encountered at the elevation a\
nticipated. A pilot hole has been drilled and sound material was found \
within 450mm(18in).

1. Excavate to sound material.
2. Maintain the footing minimum embedment of 150mm (6in) in rock a\
nd 300mm (1 ft) in shale.
3. Thicken the footing, but maintain the reinforcing steel mat ele\
vation as shown on the plans."
 WITH recommendation [8] := "The spread footing problem was caused by \
unsound material or the bedrock not being encountered at the elevation a\
nticipated. A pilot hole has been drilled and sound material was not fo\
und within 450mm(18in).

Consult District Engineer for appropriate solution."
 WITH recommendation [9] := "The spread footing problem was caused by \
unsound material or the bedrock not being encountered at the elevation a\
nticipated.

Drill a probe hole to determine the depth to sound material.

If the depth to sound material is greater than 450mm (18in):
Consult District Engineer for appropriate solution.

If the depth to sound material is less than or equal to 450mm(18in):
1. Excavate to sound material.
2. Maintain the footing minimum embedment of 150mm(6in) in rock and 300\
mm (1 ft) in shale.
3. Thicken the footing, but maintain the reinforcing steel mat elevatio\
n as shown on the plans."
 WITH recommendation [10] := "The horizontal mislocation of the pile i\
s within the Specifications 704.04d. In addition, the mislocation does \
not create an edge distance or a pile spacing problem.

Consult District Engineer for any additional recommendations."
 WITH recommendation [11] := "The horizontal mislocation of the pile a\
nd the edge distance are within the specifications. However, the misloc\
ation created a pile spacing problem.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [12] := "The horizontal mislocation of the pile a\
nd the pile spacing are within the specifications. However, the misloca\
tion created an edge distance problem.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [13] := "The mislocation of the pile is within sp\
ecifications. However, the mislocation created a pile spacing and edge d\
istance problem.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [14] := "The mislocation of the pile is not withi\
n specifications. However, the pile spacing and edge distance specific\
ations have been met.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [15] := "The mislocation of the pile is not withi\
n specifications. Due to this mislocation the pile spacing specificatio\
n has also been violated. However, the edge distance specification is m\
et.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [16] := "The mislocation of the pile is not withi\
n specifications. Due to this mislocation the edge distance specificat\
ion has also been violated. However, the pile spacing specification is \
met.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [17] := "The mislocation of the pile, the pile sp\
acing and the edge
distance specifications have all been violated.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [18] := "The mislocation of the pile is within th\
e specifications. In addition, the mislocation does not create an edge \
distance or a pile spacing problem.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult District Engineer for any additional recommendations."
 WITH recommendation [19] := "The mislocation of the pile and the edge\
 distance are within the specifications. However, the mislocation creat\
ed a pile spacing problem.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [20] := "The mislocation of the pile and the pile\
 spacing are within the specifications. However, the mislocation create\
d an edge distance problem.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [21] := "The mislocation of the pile is within sp\
ecifications. However, the mislocation created a pile spacing and edge \
distance problem.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [22] := "The mislocation of the pile is not withi\
n specifications. However, the pile spacing and edge distance specifica\
tions have been met.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [23] := "The mislocation of the pile is not withi\
n specifications. Due to this mislocation the pile spacing specificatio\
n has also been violated. However, the edge distance specification is m\
et.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
 WITH recommendation [24] := "The mislocation of the pile is not withi\
n specifications. Due to this mislocation the edge distance specificati\
on has also been violated. However, the pile spacing specification is m\
et.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
WITH recommendation [25] := "The mislocation of the pile, the pile sp\
acing and the edge
distance specifications have all been violated.

Since the piles were suspected to have been deflected, predrilling or je\
tting may be needed.

Consult the District Engineer for the appropriate solution."
WITH recommendation [26] := "The piles have reached sufficient depth \
below the assumed scour line. If adequate bearing has been obtained, st\
op driving at this depth.

If only one pile within a footing is driving short, boulders or some oth\
er type of obstruction has been hit. In this case, consult with the Di\
strict Engineer for appropriate solution."
WITH recommendation [27] := "Either an assumed scour line is not avai\
lable or the piles have not reached sufficient depth below the assumed s\
cour line.

In either case, the District Engineer should be consulted for appropriat\
e solution."
WITH recommendation [28] := "A sufficient percentage of the pile has \
been driven.
The recommendation is to stop driving at this depth.

However, if only one pile within a footing is driving short, boulders or\
some other type of obstruction has been hit. In this case, consult the\
District Engineer for appropriate solution."
WITH recommendation [29] := "A sufficient percentage of the pile has \
not been driven.
The recommendation is to consult with the District Engineer for appropri\
ate solution."
WITH recommendation [30] := "Since the pile is not obtaining adequate\
capacity and it is a
friction pile, the Geologist should be consulted about using the Pile Dr\
iving Analyzer (PDA)."
WITH recommendation [31] := "There is an absolute minimum length of p\
ile based on structural stability. The pile has not been driven to this\
depth.

Consult the Bridge Office for appropriate solution."
WITH recommendation [32] := "There is an absolute minimum length of p\
ile based on structural stability. The pile has been driven to this dep\
th.

Consult District Engineer if you have other concerns."
WITH recommendation [33] := "Since the footing has been poured, the p\
ossible solutions are very specific to the particular situation.

Therefore, consult District Engineer for appropriate solutions."
WITH recommendation [100] := "The information given is either incompl\
ete or no repair recommendation matches the given input.

Check input and run program again.
Update of this error type and repair procedure may be necessary."

```
AGENDA
 1. repair 1 OF Possible Repairs
 2. repair 2 OF Possible Repairs
 3. repair 3 OF Possible Repairs
 4. repair 4 OF Possible Repairs
 5. repair 5 OF Possible Repairs
 6. repair 6 OF Possible Repairs
 7. repair 7 OF Possible Repairs
 8. repair 8 OF Possible Repairs
 9. repair 9 OF Possible Repairs
 10. repair 10 OF Possible Repairs
 11. repair 11 OF Possible Repairs
 12. repair 12 OF Possible Repairs
 13. repair 13 OF Possible Repairs
 14. repair 14 OF Possible Repairs
 15. repair 15 OF Possible Repairs
 16. repair 16 OF Possible Repairs
 17. repair 17 OF Possible Repairs
 18. repair 18 OF Possible Repairs
 19. repair 19 OF Possible Repairs
 20. repair 20 OF Possible Repairs
 21. repair 21 OF Possible Repairs
 22. repair 22 OF Possible Repairs
 23. repair 23 OF Possible Repairs
 24. repair 24 OF Possible Repairs
 25. repair 25 OF Possible Repairs
 26. repair 26 OF Possible Repairs
 27. repair 27 OF Possible Repairs
 28. repair 28 OF Possible Repairs
 29. repair 29 OF Possible Repairs
 30. repair 30 OF Possible Repairs
 31. repair 31 OF Possible Repairs
 32. repair 32 OF Possible Repairs
 33. repair 33 OF Possible Repairs
 34. repair 100 OF Possible Repairs

! DEMON GROUP:  filename OF getfile

DEMON for saving
IF filename OF save output report <> filename OF report
THEN Save Button := TRUE

! DEMON GROUP:  repair 1 OF Possible Repairs

DEMON recommendation 1
IF repair 1 OF Possible Repairs
THEN text OF result := recommendation[ 1]
AND text OF Why? text := Why[ 1]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "The distance the footing is horizon\
tally mislocated
due to the cofferdam interference is:  ", TO STRING( horizontal mislocat\
ion), text OF units1)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 1]
AND action OF report IS close

! DEMON GROUP:  repair 2 OF Possible Repairs

DEMON recommendation 2
IF repair 2 OF Possible Repairs
THEN text OF result := recommendation[ 2]
AND text OF Why? text := Why[ 2]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "The distance the footing is horizon\
tally mislocated
due to the cofferdam interference is:  ", TO STRING( horizontal mislocat\
ion), text OF units1)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 2]
AND action OF report IS close

! DEMON GROUP:  repair 3 OF Possible Repairs

DEMON recommendation 3
IF repair 3 OF Possible Repairs
THEN text OF result := recommendation[ 3]
AND text OF Why? text := Why[ 3]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 3]
AND action OF report IS close

! DEMON GROUP:  repair 4 OF Possible Repairs

DEMON recommendation 4
IF repair 4 OF Possible Repairs
THEN text OF result := recommendation[ 4]
AND text OF Why? text := Why[ 4]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 4]
AND action OF report IS close

! DEMON GROUP:  repair 5 OF Possible Repairs

DEMON recommendation 5
IF repair 5 OF Possible Repairs
THEN text OF result := recommendation[ 5]
AND text OF Why? text := Why[ 5]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
```

```
AND write line OF report := CONCAT( "The bridge is: ", TO STRING( Bridge\
))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 5]
AND action OF report IS close

! DEMON GROUP: repair 6 OF Possible Repairs

DEMON recommendation 6
IF repair 6 OF Possible Repairs
THEN text OF result := recommendation[ 6]
AND text OF Why? text := Why[ 6]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is: ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "The bridge is: ", TO STRING( Bridge\
))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 6]
AND action OF report IS close

! DEMON GROUP: repair 7 OF Possible Repairs

DEMON recommendation 7
IF repair 7 OF Possible Repairs
THEN text OF result := recommendation[ 7]
AND text OF Why? text := Why[ 7]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is: ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "A probe hole was: ", TO STRING( Pro\
be Hole))
AND write line OF report := CONCAT( "The depth to sound material is: ", \
TO STRING( depth to sound material), text OF units8)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 7]
AND action OF report IS close

! DEMON GROUP: repair 8 OF Possible Repairs

DEMON recommendation 8
IF repair 8 OF Possible Repairs
THEN text OF result := recommendation[ 8]
AND text OF Why? text := Why[ 8]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is: ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "A probe hole was: ", TO STRING( Pro\
be Hole))
AND write line OF report := CONCAT( "The depth to sound material is: ", \
TO STRING( depth to sound material), text OF units8)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 8]
AND action OF report IS close

! DEMON GROUP: repair 9 OF Possible Repairs

DEMON recommendation 9
IF repair 9 OF Possible Repairs
THEN text OF result := recommendation[ 9]
AND text OF Why? text := Why[ 9]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is: ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( "The cause of the problem is: ", TO \
STRING( cause OF Spread Footing Problem))
AND write line OF report := CONCAT( "A probe hole was: ", TO STRING( Pro\
be Hole))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 7]
AND action OF report IS close

! DEMON GROUP: repair 10 OF Possible Repairs

DEMON recommendation 10
IF repair 10 OF Possible Repairs
THEN text OF result := recommendation[ 10]
AND text OF Why? text := Why[ 2]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is: ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is: ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is: ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s : ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 10]
AND action OF report IS close

! DEMON GROUP: repair 11 OF Possible Repairs

DEMON recommendation 11
IF repair 11 OF Possible Repairs
THEN text OF result := recommendation[ 11]
AND text OF Why? text := Why[ 11]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
```

```
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 11]
AND action OF report IS close

! DEMON GROUP:  repair 12 OF Possible Repairs

DEMON recommendation 12
IF repair 12 OF Possible Repairs
THEN text OF result := recommendation[ 12]
AND text OF Why? text := Why[ 12]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 12]
AND action OF report IS close

! DEMON GROUP:  repair 13 OF Possible Repairs

DEMON recommendation 13
IF repair 13 OF Possible Repairs
THEN text OF result := recommendation[ 13]
AND text OF Why? text := Why[ 13]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 13]
AND action OF report IS close

! DEMON GROUP:  repair 14 OF Possible Repairs

DEMON recommendation 14
IF repair 14 OF Possible Repairs
THEN text OF result := recommendation[ 14]
AND text OF Why? text := Why[ 14]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 14]
AND action OF report IS close

! DEMON GROUP:  repair 15 OF Possible Repairs

DEMON recommendation 15
IF repair 15 OF Possible Repairs
THEN text OF result := recommendation[ 15]
AND text OF Why? text := Why[ 15]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 15]
AND action OF report IS close

! DEMON GROUP:  repair 16 OF Possible Repairs

DEMON recommendation 16
IF repair 16 OF Possible Repairs
THEN text OF result := recommendation[ 16]
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```
AND text OF Why? text := Why[ 16]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 16]
AND action OF report IS close

! DEMON GROUP:  repair 17 OF Possible Repairs

DEMON recommendation 17
IF repair 17 OF Possible Repairs
THEN text OF result := recommendation[ 17]
AND text OF Why? text := Why[ 17]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 17]
AND action OF report IS close

! DEMON GROUP:  repair 18 OF Possible Repairs

DEMON recommendation 18
IF repair 18 OF Possible Repairs
THEN text OF result := recommendation[ 18]
AND text OF Why? text := Why[ 18]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 18]
AND action OF report IS close

! DEMON GROUP:  repair 19 OF Possible Repairs

DEMON recommendation 19
IF repair 19 OF Possible Repairs
THEN text OF result := recommendation[ 19]
AND text OF Why? text := Why[ 19]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 19]
AND action OF report IS close

! DEMON GROUP:  repair 20 OF Possible Repairs

DEMON recommendation 20
IF repair 20 OF Possible Repairs
THEN text OF result := recommendation[ 20]
AND text OF Why? text := Why[ 20]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 20]
```

```
AND action OF report IS close

! DEMON GROUP:  repair 21 OF Possible Repairs

DEMON recommendation 21
IF repair 21 OF Possible Repairs
THEN text OF result := recommendation[ 21]
AND text OF Why? text := Why[ 21]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 21]
AND action OF report IS close

! DEMON GROUP:  repair 22 OF Possible Repairs

DEMON recommendation 22
IF repair 22 OF Possible Repairs
THEN text OF result := recommendation[ 22]
AND text OF Why? text := Why[ 22]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 22]
AND action OF report IS close

! DEMON GROUP:  repair 23 OF Possible Repairs

DEMON recommendation 23
IF repair 23 OF Possible Repairs
THEN text OF result := recommendation[ 23]
AND text OF Why? text := Why[ 23]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 23]
AND action OF report IS close

! DEMON GROUP:  repair 24 OF Possible Repairs

DEMON recommendation 24
IF repair 24 OF Possible Repairs
THEN text OF result := recommendation[ 24]
AND text OF Why? text := Why[ 24]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 24]
AND action OF report IS close

! DEMON GROUP:  repair 25 OF Possible Repairs

DEMON recommendation 25
IF repair 25 OF Possible Repairs
THEN text OF result := recommendation[ 25]
AND text OF Why? text := Why[ 25]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The horizontal mislocation is:  ", \
TO STRING( horizontal mislocation), text OF units1)
AND write line OF report := CONCAT( "The actual pile spacing is: ", TO S\
TRING( spacing OF Pile), text OF units5)
AND write line OF report := CONCAT( "The actual edge distance is:  ", TO\
 STRING( edge distance OF Pile), text OF units6)
AND write line OF report := CONCAT( "The diameter or width of the pile i\
s :  ", TO STRING( diameter_width OF Pile), text OF units4)
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AND write line OF report := CONCAT( "The length of the pile is: ", TO ST\
RING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 25]
AND action OF report IS close

! DEMON GROUP:  repair 26 OF Possible Repairs

DEMON recommendation 26
IF repair 26 OF Possible Repairs
THEN text OF result := recommendation[ 26]
AND text OF Why? text := Why[ 26]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The scour line is: ", TO STRING( Sc\
our Line))
AND write line OF report := CONCAT( "The depth driven below the scour li\
ne is:  ", TO STRING( depth below scour line), text OF units7)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 26]
AND action OF report IS close

! DEMON GROUP:  repair 27 OF Possible Repairs

DEMON recommendation 27
IF repair 27 OF Possible Repairs
THEN text OF result := recommendation[ 27]
AND text OF Why? text := Why[ 27]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The scour line is: ", TO STRING( Sc\
our Line))
AND write line OF report := CONCAT( "The depth driven below the scour li\
ne is:  ", TO STRING( depth below scour line), text OF units7)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 27]
AND action OF report IS close

! DEMON GROUP:  repair 28 OF Possible Repairs

DEMON recommendation 28
IF repair 28 OF Possible Repairs
THEN text OF result := recommendation[ 28]
AND text OF Why? text := Why[ 28]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The specified length of the pile is\
: ", TO STRING( length OF Pile), text OF units3)
AND write line OF report := CONCAT( "The vertical distance that the pile\
 is short of plan elevation is: ", TO STRING( vertical mislocation), tex\
t OF units2)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 28]
AND action OF report IS close

! DEMON GROUP:  repair 29 OF Possible Repairs

DEMON recommendation 29
IF repair 29 OF Possible Repairs
THEN text OF result := recommendation[ 29]
AND text OF Why? text := Why[ 29]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The specified length of the pile is\
: ", TO STRING( length OF Pile), text OF units3)
AND write line OF report := CONCAT( "The vertical distance that the pile\
 is short of plan elevation is: ", TO STRING( vertical mislocation), tex\
t OF units2)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 29]
AND action OF report IS close

! DEMON GROUP:  repair 30 OF Possible Repairs

DEMON recommendation 30
IF repair 30 OF Possible Repairs
THEN text OF result := recommendation[ 30]
AND text OF Why? text := Why[ 30]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The pile resistance is:  ", TO STRI\
NG( resistance OF Pile))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 30]
AND action OF report IS close

! DEMON GROUP:  repair 31 OF Possible Repairs

DEMON recommendation 31
IF repair 31 OF Possible Repairs
THEN text OF result := recommendation[ 31]
AND text OF Why? text := Why[ 31]
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AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The specified length of the pile is\
: ", TO STRING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 31]
AND action OF report IS close

! DEMON GROUP:  repair 32 OF Possible Repairs

DEMON recommendation 32
IF repair 32 OF Possible Repairs
THEN text OF result := recommendation[ 32]
AND text OF Why? text := Why[ 32]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := CONCAT( " The cause of the problem is: ", TO\
 STRING( cause OF Pile Footing Pile Bent Problem))
AND write line OF report := CONCAT( "The bridge is:  ", TO STRING( Bridg\
e))
AND write line OF report := CONCAT( "The specified length of the pile is\
: ", TO STRING( length OF Pile), text OF units3)
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 32]
AND action OF report IS close

! DEMON GROUP:  repair 33 OF Possible Repairs

DEMON recommendation 33
IF repair 33 OF Possible Repairs
THEN text OF result := recommendation[ 33]
AND text OF Why? text := Why[ 33]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := CONCAT( "The substructure unit with a proble\
m is:  ", TO STRING( substructure unit with problem))
AND write line OF report := CONCAT( "The footing is: ", TO STRING( footi\
ng))
AND write line OF report := " "
AND write line OF report := " "
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 33]
AND action OF report IS close

! DEMON GROUP:  repair 100 OF Possible Repairs

DEMON recommendation 100
IF repair 100 OF Possible Repairs
THEN text OF result := recommendation[ 100]
AND text OF Why? text := Why[ 100]
AND action OF report IS open new
AND time := NOW
AND write line OF report := "PIER FOOTING EXPERT SYSTEM OUTPUT
REPORT"
AND write line OF report := ""
AND write line OF report := CONCAT( "TIME OF RUN: ", TO STRING( time))
AND write line OF report := ""
AND write line OF report := ""
AND write line OF report := "Conclusions & Recommendations "
AND write line OF report := " "
AND write line OF report := recommendation[ 100]
AND action OF report IS close

! DEMON GROUP:  type OF Units

DEMON for english units
IF type OF Units IS english
THEN text OF units1 := "inches"
AND text OF units2 := "feet"
AND text OF units3 := "feet"
AND text OF units4 := "inches"
AND text OF units5 := "inches"
AND text OF units6 := "inches"
AND text OF units7 := "feet"
AND text OF units8 := "inches"
DEMON for metric units
IF type OF Units IS metric
THEN text OF units1 := "millimeters"
AND text OF units2 := "meters"
AND text OF units3 := "meters"
AND text OF units4 := "millimeters"
AND text OF units5 := "millimeters"
AND text OF units6 := "millimeters"
AND text OF units7 := "meters"
AND text OF units8 := "millimeters"
! DEMON GROUP:  output OF window

DEMON showhide Why? Window
IF  CONF(output OF Why? Window) = -1
THEN visible OF Why? Window := FALSE
ELSE visible OF Why? Window := TRUE

DEMON showhide Report Window
IF  CONF(output OF Report Window) = -1
THEN visible OF Report Window := FALSE
ELSE visible OF Report Window := TRUE

DEMON showhide Database Input Option Window
IF  CONF(output OF Database Input Option Window) = -1
THEN visible OF Database Input Option Window := FALSE
ELSE visible OF Database Input Option Window := TRUE

! RULE GROUP:  repair 1 OF Possible Repairs

RULE 1
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND cause OF Spread Footing Problem IS interference with cofferdam
AND horizontal mislocation <= horizontal mislocation expert's specificat\
ion
THEN repair 1 OF Possible Repairs

! RULE GROUP:  repair 2 OF Possible Repairs

RULE 2
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND cause OF Spread Footing Problem IS interference with cofferdam
AND horizontal mislocation > horizontal mislocation expert's specificati\
on
THEN repair 2 OF Possible Repairs

! RULE GROUP:  repair 3 OF Possible Repairs

RULE 3
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND (cause OF Spread Footing Problem IS incorrect excavation OR cause OF\
 Spread Footing Problem IS overbreakage)
THEN repair 3 OF Possible Repairs

! RULE GROUP:  repair 4 OF Possible Repairs

RULE 4
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND cause OF Spread Footing Problem IS fissures
THEN repair 4 OF Possible Repairs

! RULE GROUP:  repair 5 OF Possible Repairs
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RULE 5
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND cause OF Spread Footing Problem IS high bedrock
AND Bridge IS over a stream
THEN repair 5 OF Possible Repairs

! RULE GROUP: repair 6 OF Possible Repairs

RULE 6
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND cause OF Spread Footing Problem IS high bedrock
AND Bridge IS not over a stream
THEN repair 6 OF Possible Repairs

! RULE GROUP: repair 7 OF Possible Repairs

RULE 7
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND (cause OF Spread Footing Problem IS low bedrock OR cause OF Spread F\
ooting Problem IS unsound material)
AND Probe Hole IS drilled
AND depth to sound material <= depth to sound material expert's specific\
ation
THEN repair 7 OF Possible Repairs

! RULE GROUP: repair 8 OF Possible Repairs

RULE 8
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND (cause OF Spread Footing Problem IS low bedrock OR cause OF Spread F\
ooting Problem IS unsound material)
AND Probe Hole IS drilled
AND depth to sound material > depth to sound material expert's specifica\
tion
THEN repair 8 OF Possible Repairs

! RULE GROUP: repair 9 OF Possible Repairs

RULE 9
IF substructure unit with problem IS spread footing
AND footing IS not poured
AND (cause OF Spread Footing Problem IS low bedrock OR cause OF Spread F\
ooting Problem IS unsound material)
AND Probe Hole IS not drilled
THEN repair 9 OF Possible Repairs

! RULE GROUP: repair 10 OF Possible Repairs

RULE 10
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 10 OF Possible Repairs

! RULE GROUP: repair 11 OF Possible Repairs

RULE 11
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 11 OF Possible Repairs

! RULE GROUP: repair 12 OF Possible Repairs

RULE 12
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 12 OF Possible Repairs

! RULE GROUP: repair 13 OF Possible Repairs

RULE 13
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 13 OF Possible Repairs

! RULE GROUP: repair 14 OF Possible Repairs

RULE 14
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 14 OF Possible Repairs

! RULE GROUP: repair 15 OF Possible Repairs

RULE 15
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 15 OF Possible Repairs

! RULE GROUP: repair 16 OF Possible Repairs

RULE 16
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 16 OF Possible Repairs

! RULE GROUP: repair 17 OF Possible Repairs

RULE 17
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND (cause OF Pile Footing Pile Bent Problem IS staking OR cause OF Pile\
Footing Pile Bent Problem IS drift)
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 17 OF Possible Repairs

! RULE GROUP: repair 18 OF Possible Repairs

RULE 18
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 18 OF Possible Repairs

! RULE GROUP: repair 19 OF Possible Repairs

RULE 19
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile < spacing specification

AND edge distance OF Pile >= edge distance specification
THEN repair 19 OF Possible Repairs

! RULE GROUP: repair 20 OF Possible Repairs

RULE 20
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 20 OF Possible Repairs

! RULE GROUP: repair 21 OF Possible Repairs

RULE 21
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation <= horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 21 OF Possible Repairs

! RULE GROUP: repair 22 OF Possible Repairs

RULE 22
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 22 OF Possible Repairs

! RULE GROUP: repair 23 OF Possible Repairs

RULE 23
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile >= edge distance specification
THEN repair 23 OF Possible Repairs

! RULE GROUP: repair 24 OF Possible Repairs

RULE 24
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile >= spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 24 OF Possible Repairs

! RULE GROUP: repair 25 OF Possible Repairs

RULE 25
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS boulder deflection
AND horizontal mislocation > horizontal mislocation specification
AND spacing OF Pile < spacing specification
AND edge distance OF Pile < edge distance specification
THEN repair 25 OF Possible Repairs

! RULE GROUP: repair 26 OF Possible Repairs

RULE 26
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS penetration
AND Bridge IS over a stream
AND Scour Line IS available
AND depth below scour line > depth below scour line expert's specificati\
on
THEN repair 26 OF Possible Repairs

! RULE GROUP: repair 27 OF Possible Repairs

RULE 27a
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS penetration
AND Bridge IS over a stream
AND Scour Line IS available
AND depth below scour line <= depth below scour line expert's specificat\
ion
THEN repair 27 OF Possible Repairs

RULE 27b
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS penetration
AND Bridge IS over a stream
AND Scour Line IS not available
THEN repair 27 OF Possible Repairs

! RULE GROUP: repair 28 OF Possible Repairs

RULE 28
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS penetration
AND Bridge IS not over a stream
AND vertical mislocation <= vertical mislocation expert's specification
THEN repair 28 OF Possible Repairs

! RULE GROUP: repair 29 OF Possible Repairs

RULE 29
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS penetration
AND Bridge IS not over a stream
AND vertical mislocation > vertical mislocation expert's specification
THEN repair 29 OF Possible Repairs

! RULE GROUP: repair 30 OF Possible Repairs

RULE 30
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS capacity
AND resistance OF Pile IS friction
THEN repair 30 OF Possible Repairs

! RULE GROUP: repair 31 OF Possible Repairs

RULE 31
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS min length
AND length OF Pile <= minimum length expert's specification
THEN repair 31 OF Possible Repairs

! RULE GROUP: repair 32 OF Possible Repairs

RULE 32
IF (substructure unit with problem IS pile footing OR substructure unit \
with problem IS pile bent)
AND footing IS not poured
AND cause OF Pile Footing Pile Bent Problem IS min length
AND length OF Pile > minimum length expert's specification
THEN repair 32 OF Possible Repairs

! RULE GROUP: repair 33 OF Possible Repairs

RULE 33
IF (substructure unit with problem IS spread footing OR substructure uni\
t with problem IS pile footing OR substructure unit with problem IS pile\
bent)
AND footing IS poured
THEN repair 33 OF Possible Repairs

! RULE GROUP: repair 100 OF Possible Repairs

RULE 100
IF All Information Given
THEN repair 100 OF Possible Repairs
ELSE CHAIN "foundatn.knb"

END

Appendix D - Knowledge Sources: Panel of Experts & Panel of Users

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Appendix E - Case Histories

CASE	PROJECT NO.	BRIDGE NO.	COUNTY	ERROR LOCATION	CAUSE OF ERROR	REPAIR
TLF102	670-105 K-1652-01	670-105-0.51&0.58	WYANDOTTE	ANCHOR BOLT WELLS	MISLOCATED	USE THE EXISTING ANCHOR BOLT WELLS BY MODIFYING THE BEARINGS IF POSSIBLE. IF NEW ANCHOR BOLT WELLS MUST BE DRILLED, THE CONTRACTOR SHOULD LOCATE THE REINFORCING STEEL USING A PACHOMETER PRIOR TO ANY DRILLING. SOME PROBLEMS REQUIRE BOTH APPROACHES DUE TO REINFORCING STEEL PREVENTING T PROPER RELOCATION OF THE ANCHOR BOLTS.
TLF104	670-105 K-2888-01	670-105-1.28	WYANDOTTE	ANCHOR BOLT WELLS	MISLOCATED BECAUSE OF DISCREPANCY IN THE PLANS BETWEEN THE SUPERSTRUCTURE AND SUBSTRUCTURE PLANS	GROUT IN THE MISLOCATED WELLS, GRIND THE TOP OF THE PIER CAP TO PROVIDE A LEVEL BEARING SEAT AND THEN REDRILL THE ANCHOR BOLT WELLS IN THE PROPER LOCATION.
TLF110	670-105 K-2888-02	670-105-1.29	WYANDOTTE	ANCHOR BOLTS	GIRDER PLACED WITH GUSSET PLATE THAT NOW COVERS ANCHOR BOLTS MAKING THEM INACCESSIBLE	WELD TABS TO THE MASONRY PLATE OF THE BEARING DEVICE AND ENLARGE THE EXISTING PREFORMED ANCHOR BOLT WELLS TO ENCOMPASS THE NEW POSITION. THE CONTRACTOR AT THE TIME OF ERECTION, COULD HAVE ENLARGED THE PREFORMED ANCHOR BOLT WELLS AND INSERTED THE ANCHOR BOLTS BEFORE SETTIG THE GIRDER ON THE BEARING DEVICE, AND THUS AVOIDED THIS ENTIRE PROBLEM.
TLF515	670-105 K-1655-02	670-105-1.25	WYANDOTTE	ANCHOR BOLT WELLS	INPROPER GROUT, FREEZE/THAW	ALL ANCHOR BOLT WELLS SHALL BE CHECKED FOR FULLNESS. IN ALL BUT ONE CASE, THE EDGE OF THE 4" ANCHOR BOLT WELL IS NEAR THE EDGE OF THE MASONRY PLATE. CHIP THE CONCRETE AWAY FROM THE BEARING SEAT CLOSEST TO THE WELL, REMOVE BY VACUUMING ANY WATER OR LOOSE MATERIALS FROM THE WELL, REFILL TO THE TO WITH AN APPROVED EPOXY GROUT.
TLF510	81-72 K-4428-01	81-72-17.03	OTTAWA	BEARING SEAT ELEV.	EXCEED ALLOW. TOLERANCE	HIGH BEARING SEATS SHOULD BE BROUGHT BACK WITHIN TOLERANCE BY GRINDING. LOW BEARING SEATS SHOULD BE BROUGHT BACK WITHIN TOLERANCE BY PLACING STEEL SHIM PLATES. THE MINIMUM SHIM PLATE REQUIREMENTS ARE ASTM A709 GR36 STEEL. MILL CERTIFICATION SHOULD BE REQUIRED. EXTRA CARE NEEDS TO BE TAKEN WHEN THE PRESTRESS BEAMS ARE PLACED AS THE ELASTOMERIC BEARING PADS ARE THE SAME DIMENSIONS. THE STEEL SHIM PLATES MUST BE LOCATED DIRECTLY UNDER THE ELASTOMERIC PADS. THE PADS CANNOT HANG OVER THE STEEL PLATES IN ANY DIRECTION. THE STEEL SHIM PLATES WILL BE GALVANIZED IN ACCORDANCE WITH KDO STANDARD SPECIFICATIONS. AN OPTION TO THE STEEL SHIM PLATE IS A GROUT PAD. THE GROUT SHOULD BE 5000 PSI NON-SHRINK GROUT. POLY OR STEEL REINFORCING FIBERS MAY BE REQUIRED. THE GROUT PAD SHOULD EXTEND 1" OUT FROM THE ELASTOMERIC PAD ALONG ALL SIDES.
TLF112	670-105 K-1655-01		WYANDOTTE	MASONRY PLATES FOR FIXED BEARING	PLATE IS 32", GIRDER BOTTOM FLANGE IS 34"	ADD 4"X4"X1" EARS .
TLF518				BEARING SEATS	CONTRACTOR CONSTRUCTED TOO LOW	ATTACH SHIM PLATE.
TLF511	670-105 K-1655-03	670-105-1.25	WYANDOTTE	BEARING STIFFENER	ALIGNMENT OF THE BEARING STIFFENER PLATE WITH THE CAST-IN ANCHOR BOLT HOLES	RAISE AND SUPPORT BEAMS AND REMOVE LAMINATED ELASTOMERIC BEARING PAD. REMOVE WELDS ATTACHING EXISTING SOLE PLATES TO GIRDER FLANGES. GRIND FLANGES AND SOLE PLATES TO SMOOTH SURFACES WHERE WELDS HAVE BEEN REMOVED. SANDBLAST AND CLEAN FLANGES, WEBS AND SOLE PLATES AT LOCATIONS OF NEW WELDED CONNECTIONS FOR SOLE AND STIFFENER PLATES. MOVE BEARING DEVICES SO THAT THEIR CENTERLINES INTERSECT CENTERLINES OF PIER AND BEAMS AND WELD SOLE PLATES TO FLANGES OF BEAMS. INSTALL STUB STIFFENER PLATES. CLEAN AND APPLY PAINT TO PAINTED SURFACES OF BEAM AND BEARING DEVICE WHIC WERE DAMAGED DURING THIS WORK. INSTALL LAMINATED PADS SO THAT THEY ARE CENTERED UNDER SOLE PLATES. LOWER BEAMS ONTO PADS. INSTALL AND GROUT ANCHOR BOLTS.
TLF519	35-46K-4088-02	35-46-14.35	JOHNSON	BEARING STIFFENERS	WELDED IN PLACE AT INVERTED BEVEL	FABRICATE NEW SEPERATOR WITH BENT PLATE CONNECTIONS AT EACH END.
TLF105	670-105 K-1655-01		WYANDOTTE	STIFFENER	PLACED UPSIDE DOWN	NEW STIFFENERS WILL BE FABRICATED. THE EXISTING STIFFENERS WILL BE REMOVED BY MEANS OF AIR ARC GOUGING. THE WEB PLATE SHALL BE GROUND SMOOTH AFTER EXISTING STIFFENER REMOVAL. A NEW STIFFENER WILL BE INSTALLED USING A WELDER CERTIFIED BY KDOT.

CASE	PROJECT NO.	BRIDGE NO.	COUNTY	ERROR LOCATION	CAUSE OF ERROR	REPAIR
VC100	670-105 K-1655-01		WYANDOTTE	STIFFENER	INSTALLED UPSIDE DOWN	REMOVE EXISTING STIFFENER BY USING AIR-ARC CARBON GOUGING UP TO TOE OF EXISTING WELD. THE REMAINING STIFFENER MATERIAL IS TO BE REMOVED BY GRINDIN SO AS TO PROVIEDE A SMOOTH SURFACE SUITABLE FOR ATTACHING NEW STIFFENER. GRIND PAINT APPROXIMATELY 6" FROM WELD AREA BOTH SIDES. ALL WELDING SHALL BE DONE BY A WELDER APPROVED BY KDOT FOR FCM FIELD WELDING. THE AREA OF STIFFENER REMOVAL SHALL BE INSPECTED AS TO SUITABILITY PRIOR TO FITTING NEW STIFFENER (CLEANLINESS, ETC., PROVIDING ADDITIONAL GRINDING AS REQUIRED). PREHEAT (PRIOR TO TACKING) SHALL BE AS REQUIRED IN WELDING PROCEDURE QUALIFICATION. FINAL WELD INSPECTION SHALL BE BY KDOT FIELD INSPECTORS.
TLF517	670-105 K-1655-01		WYANDOTTE	FRACTURE CRITICAL STIFFENER		REMOVE EXISTING STIFFENER BY USING AIR-ARC CARBON GOUGING UP TO TOE OF EXISTING WELD. THE REMAINING STIFFENER MATERIAL IS TO BE REMOVED BY GRINDIN SO AS TO PROVIEDE A SMOOTH SURFACE SUITABLE FOR ATTACHING NEW STIFFENER. GRIND PAINT APPROXIMATELY 6" FROM WELD AREA BOTH SIDES. ALL WELDING SHALL BE DONE BY A WELDER APPROVED BY KDOT FOR FCM FIELD WELDING. THE AREA OF STIFFENER REMOVAL SHALL BE INSPECTED AS TO SUITABILITY PRIOR TO FITTING NEW STIFFENER (CLEANLINESS, ETC., PROVIDING ADDITIONAL GRINDING AS REQUIRED). PREHEAT (PRIOR TO TACKING) SHALL BE AS REQUIRED IN WELDING PROCEDURE QUALIFICATION. FINAL WELD INSPECTION SHALL BE BY KDOT FIELD INSPECTORS.
TLF506	670-105 K-2888-01	670-105-1.28&1.29	WYANDOTTE	COLUMN	TOP OF COLUMN NOT LEVEL	GRIND THE TOP LEVEL AND ADD A STEEL PLATE. THE PLATE WILL BE OF A-36 STEEL, GALVANIZED OR PAINTED WITH INORGANIC ZINC PAINT.
TLF508	670-105 K-1656-01	670-105-1.76	WYANDOTTE	COLUMN	MISLOCATED BY 10"	REMOVE EXISTING COLUMN AND FOOTING. USE EXISTING PILING TO CONSTRUCT NEW COLUMN AND FOOTING.
TLF108	75-63 K-3436-01	75-63-26.71	MONTGOMERY	DRILLED SHAFT	A LARGE AREA OF UNSOUND CONCRETE CAUSED BY EXCESSIVE INFLOW OF WATER DURING CONCRETE PLACEMENT.	PRESSURE GROUT THE CORE HOLES IN THE DRILLED SHAFT. REDESIGN FOOTING.
TLF 103	670-105 K-2888-01	670-105-1.28	WYANDOTTE	EXPANSION JOINT	ELEVATION DIFFERENCE IN THE LONGITUDINAL EXPANSION JT.	WELD A SERIES OF VARIABLE DEPTH PLATES TO THE LOW SIDE OF THE JOINT AND GRIND SO NO TO EXCEED THE HIGH SIDE.
TLF106	670-105 K-1655-01	670-105-1.31&1.38	WYANDOTTE	EXPANSION BEARING DEVICES	PLAN DISCREPANCY AND FABRICATION CHANGES	USE BEARING DEVICES AS FABRICATED. EXISTING ANCHOR BOLT WELLS SHOULD BE FILLED AND NEW HOLES DRILLED IN THE PIER CAPS.
TLF513				EXPANSION JOINT SUPPORT ASSEMBLY	LACK OF VERTICAL ADJUSTMENT	GRIND OR FLAME CUT AND GRIND THE BURRS OFF OF THE THE TOP OF THE VERTICAL LEG UNTIL THEY GET THEIR REQUIRED ADJUSTMENT. REPAINT DAMAGED AREAS WITH ORGANIC ZINC.
DLJ100	670-105 K-2888-02	670-105-1.28&1.29	WYANDOTTE	EXPANSION DEVICES	CONSTRUCTION INPROPERLY	THE GAP IN THE BARRIER CURB WAS TO MATCH THE GAP IN THE EXPANSION JOINTS HOWEVER, IT EXCEEDS THIS GAP AND IS OVER THE MAXIMUM ALLOWABLE GAP OF 4". DUE TO POSSIBLE VEHICULAR SNAGGING, A COVER PLATE SHALL BE FABRICATED.
GC100	96-11-K4069-01	96-11-0.22	CHEROKEE	FALSEWORK	FALSEWORK FAILURE - 2 ADJUSTING BOLTS IN THE SUPPORT SHOES BROKE AND THE FALSEWORK SETTLED APPROXIMATELY 4".	THE SURFACE OF THE BRIDGE DECK AT TE CONSTRUCTION JOINT IS ROUGH AND WILL NEED TO BE REPAIRED. SAW CUT ACROSS THE DECK AND REMOVE THE CONCRETE 1 1/2" DEEP, 1" OF THE EXISTING CONCRETE WILL REMAIN ABOVE THE TOP REINFORCIN BARS.
TLF101	670-105 K-1655-01	670-105-1.38	WYANDOTTE	PIER/FOOTING	PIER WAS CONSTRUCTED 6.62 FEET NORTH OF THE PLAN LOCATION OF THE PIER.	REMOVE THE PIERCAP AND COLUMN AND PART OF THE FOOTING. DRIVE NEW PILING AND USED EXISTING PILE AS RECOMMENDED BY CONSULTANT.
TLF509	670-105 K-1656-01	670-105-1.29	WYANDOTTE	FOOTING	PILE INTERFERE WITH EXISTING UNDERGROUND CATTLE PASS WALLS.	REDESIGN.
TLF512	177-8 K-4357-01	177-8-18.56	BUTLER	FOOTING	BEDROCK NOT REACHED 8' BELOW BOTTOM OF FOOTING	CONTRACTOR CLEARED OUT THE LOOSE MATERIAL TO A SOLID CONDITION, AND BACKFILLED TO THE BOTTOM OF FOOTING ELEVATION WITH CONCRETE.
LRR100	670-105 K-1655-01	670-105-1.38	WYANDOTTE	PIER CAP	DETERIORATION OF CONCRETE	REMOVE CONCRETE BOX GIRDER FROM BOTH SIDES. REMOVE CAP TO THE TOP OF TH COLUMN. COMBINE THE REPLACEMENT AND WIDENING CAPS, AND ELIMINATE THE DOWEL BARS BETWEEN.
LRR100	670-105 K-1655-01	670-105-1.38	WYANDOTTE	PIER CAP	DETERIORATION OF CONCRETE	REMOVE CONCRETE BOX GIRDER FROM ONE SIDE. BRIDGE SEAT REPLACEMENT TYPE HANDLED BY SEGMENTS.

CASE	PROJECT NO.	BRIDGE NO.	COUNTY	ERROR LOCATION	CAUSE OF ERROR	REPAIR
LRR100	670-105 K-1655-01	670-105-1.38	WYANDOTTE	PIER CAP	DAMAGED BY CONTRACTOR DURING REMOVAL	CONTRACTOR REQUIRED TO HIRE AN ENGINEER, PREPARE PLANS FOR APPROVAL AND MAKE NECESSARY REPAIRS.
TLF503	670-105 K-2888-02	670-105-1.29	WYANDOTTE	PIER	CRACKS IN PIER	SAW CAP 1 " DEEP AT THE LIMITS OF REMOVAL AND CHIP OUT EXISTING CONCRETE (AT LEAST 1 1/2" BEYOND REINFORCING STEEL). REMOVAL TO BE MADE USING ONLY SMALL CHIPPING HAMMERS. FORM AND REPOUR WITH CONCRETE SIMILAR TO BRIDGE DECK SURFACING CONCRETE. APPLY KNOT APPROVED BONDING EPOXY BEFORE POURING CONCRETE.
TLF504	670-105 K-2888-01	670-105-1.29	WYANDOTTE	PIER	THE PIER IS ROTATED 3" ON EACH END	THE CONCERN IS THE NEW LOCATIONS OF THE LOADS AND ITS BALANCE ON THE PIER. THE ROTATION WHICH IS APPROXIMATELY SYMMETRICAL WILL OFFSET ON ANOTHER. THE BEARING DEVICES WILL FIT ON TOP OF THE BEAM WITHOUT EDGE DISTANCE PROBLEMS. THE LOCATIONS OF THE ANCHOR BOLT WELLS MAY REQUIRE ADJUSTMEN
TLF109	169-105 K-2878-03	169-105-2.59	WYANDOTTE	PIER	OUT OF POSITION - STAKING ERROR	REMOVE THE CONCRETE BEARING PADS DOWN TO TOP OF THE PIER BEAM, ADD SOME REINFORCING STEEL, AND POUR CONTINUOUS PADS BACK IN THE REQUIRED LOCATION MODIFY THE STEEL BEARING PLATES BY EXTENDING THE SLOTTED HOLES TO WITHIN 2" OF THE EDGE OF THE BEARING PLATES TO AVOID ENLARGING THE EXISTING ANCHOR BOLT WELLS.
TLF111	670-105 K-1655-01	670-105-1.31&1.38	WYANDOTTE	PIER CAP	ELEVATION TO HIGH	REMOVE THE CONCRETE TO AN ELEVATION APPROXIMATELY 2" BELOW FINISH GRADE AND REPLACE CONCRETE TO FINISH ELEVATION. IF HORIZONTAL BARS ARE EXPOSED, THEY MUST BE LOWERED TO PROVIDE THE NECESSARY CONCRETE COVER AND ENOU CONCRETE MUST BE REMOVED TO ALLOW FOR 1" OF CONCRETE BETWEEN THE EXISTING CONCRETE AND THE BOTTOM OF THE REINFORCING STEEL.
TLF515	670-105 K-1655-02	670-105-1.25	WYANDOTTE	PIER CAPS	CRACKED DUE TO FREEAING WATER COLLECTED IN THE ANCHOR BOLT WELLS.	REMOVE THE LOOSE AND CROCKED CONCRETE TO JUST BEHOND CRACK DEPTH OR T CLEAR THE END LOOP REINFORCING STEEL BY A MINIMUM OF 1 1/2". COAT THE EXISTIN CONCRETE AT THE CONCRETE REMOVAL LINE WITH AN APPROVED CONCRETE BONDIN EPOXY. REPLACE CONCRETE WITH CLASS AAA-AE CONCRETE. IF THE CRACK DOES N PROTRUDE PAST THE ANCHOR BOLT WELL, NO FLASEWORK TO SUPPORT THE GIRDER IS NECESSARY.
TLF500	670-105 K-1655-01	670-105-1.38	WYANDOTTE	PILE	PILES WERE DRIVEN FROM 1" - 9" OFF PLAN LOCATION	MAKE FOOTING BIGGER. EXTEND REINFORCING STEEL. MAKE SURE COLUMN IS IN CORRECT LOCATION.
TLF501	670-105 K-2888-02	670-105-1.29	WYANDOTTE	PILE	PILES WERE DRIVEN IN INCORRECT POSITION	EITHER THE FOOTING MUST BE ENLARGED TO ENCOMPASS THE PILING AS DRIVEN OR ADDITIONAL PILING DRIVEN IN PROPER POSITION.
TLF507	670-105 K-2888-01	670-105-1.29	WYANDOTTE	SPAN LENGTHS	COLUMN CENTERLINE OFF BY 1"	REMOVE THE SOLE PLATES AND REATTACH IN THE CORRECT LOCATION WITH THE ROCKER CORRECTED TEMPERATURE. AFTER REMOVAL OF THE SOLE PLATE, THE CONTRACTOR SHALL GRIND OFF ANY REMAINING WELD METAL AND THE INORGANIC ZI PAINT FROM UNDER THE NEW LOCATION PLUS 2". REATTACH SOLE PLATE BY WELDING AS STATED IN THE CONSTRUCTION PLANS. REPAINT AREA WITH ORGANIC ZINC SHOP COAT. IF THE EDGE OF THE SOLE IS BEYOND THE FRONT EDGE OF THE BEARING STIFFENER, THEN A NEW SHORT BEARING STIFFENER MUST BE INSTALLED. THE SOLEPLATE MUST BE TOTALLY COVERED BY THE BEARING STIFFENER.
LRR101	670-105 K-2888-02	670-105-1.29	WYANDOTTE	SOLE PLATES	USED 25EP3 PLATES INSTEAD OF 25EP2 PLATES	AIR ARC THE INCORRECT PLATES OFF THE GIRDERS, GRIND THE AREA CLEAN, THEN WELD THE CORRECT PLATES TO THE GIRDER AND FINALLY REPAINT THE AFFECTED AR A WITH ORGANIC ZINC-VINYL PAINT.
TLF100	670-105 K-2888-02	670-105-1.29	WYANDOTTE	TOP FLANGE OF STEEL GIRDER	FLANGES WERE DAMAGED BY THE CONTRACTOR WHILE REMOVING AN UNACCEPTABLE SECTION OF DECK THAT HAD BEEN POURED.	NOTCHES LESS THAN 1/4" - TO BE GROUND OUT SMOOTHLY. THE MAXIMUM SLOPE FOR THE GRINDING IS TO BE 1" VERTICAL TO 10" HORIZONTAL. THE GRINDING IS TO BE DON IN THE DIRECTION OF THE MAJOR STRESS (Ie. - LONGITUDINALLY ALONG THE GIRDER). A CIRCULAR GRINDER MAY BE USED IF THE REPAIR IS FINISHED WITH A BELT GRINDER THE DIRECTION OF THE MAJOR STRESS. NOTCHES DEEPER THAN 1/4" MAY NOT BE REPAIRED WITH THIS PROCEDURE WITHOUT FURTHER APPROVAL. WHEN THE REPAIR COMPLETE THE AREAS THAT HAVE BEEN GROUND SHALL BE INSPECTED BY A KDOT MATERIALS INSPECTOR. AFTER THE REPAIR HAS BEEN APPROVED, THE GROUND AREAS SHALL BE PAINTED WITH ORGANIC ZINC-VINYL PAINT.
TLF502	670-105 K-2888-02	670-105-1.29	WYANDOTTE	GUSSET PLATE	MISLOCATED HOLES BY 4"	DRILL NEW HOLES. FILL EXISTING HOLES WITH A-325 BOLTS.
TLF505	670-105 K-2888-01	670-105-1.29	WYANDOTTE	BOTTOM CHORD	MISLOCATED HOLES	A NEW BOTTOM CHORD MEMBER MUST BE FABRICATED AND INSTALLED.

CASE	PROJECT NO.	BRIDGE NO.	COUNTY	ERROR LOCATION	CAUSE OF ERROR	REPAIR
TLF107	670-105 K-1655-01	670-105-1.38	WYANDOTTE	SHEAR CONNECTORS	INADEQUATE PENETRATION IN SLAB	6" AND 7" STUDS ARE REQUIRED IN SOME LOCATIONS. WHERE 5" STUDS ARE ALREADY WELDED, THE CONTRACTOR MAY WELD SHORT STUDS ONTO THE TOP OF THE 5" STUDS OR ADD ROWS OF THE LONGER STUDS BETWEEN THE ROWS OF 5" STUDS.
TLF514	670-105 K-1655-01	670-105-1.31&1.38	WYANDOTTE	FLANGE	NOTCHES IN THE FLANGE	REPLACE THE LOST TOP COMPRESSION FLANGE PIECE WITH A NEW PLATE OF ASTM A3 OF APPROXIMATELY THE SAME SIZE. THE REPLACEMENT PLATE MAY BE WELDED WITH AWS WEL DESIGNATION B-U2. WE SUGGEST THAT A COUPON OF THE A7 STEEL BE REMOVED AND CHECKED FOR CHEMICALS TO DETERMINE ITS WELDABILITY.
TLF516	670-105 K-1655-01		WYANDOTTE	FLOOR BEAM	CONNECTION HOLES OF PLATES DO NOT ALIGN WITH HOLES IN TOP FLANGE OF GIRDER.	REMOVE EXISTING PLATES BY MEANS OF AIR ARC GOUGING ANG GRINDING. ALIGN NEW PLATES TO CORRECT POSITION, MATCH MARK FOR ALIGNMENT, MARK HOLE LOCATION REMOVE PLATE AND DRILL HOLES, RE-ATTACH PLATE TO MATCHMARK LOCATION, FIT AND WELD.
TLF113	169-105 K-2878-03	169-105-2.59	WYANDOTTE	STRINGERS	SHORT BECAUSE THEY WERE CUT TO THE HORIZONTAL DIMENSIONS SHOWN IN THE FRAMING PLAN WHICH DOES NOT ACCOUNT FOR THE VERTICAL CURVATURE OF THE BRIDGE.	SLOT HOLES TO ALLOW ERECTION, BEING CAREFUL NOT TO CREATE AN EDGE DISTANC PROBLEM.