STEEL BRIDGE FABRICATION ERRORS INDEXED EXAMPLES AND SOLUTIONS: COMBINING RULES AND CASES

By
Richard R. Greenfield
W. M. Kim Roddis

A Report on Research Sponsored by

Kansas Department of Transportation
KTRAN Project No. KU-98-8
Mid America Transportation Center
MATC/KU 98-2
National Steel Bridge Alliance

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THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
2291 Irving Hill Drive - Campus West, Lawrence, Kansas 66045

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ABSTRACT

This research focuses on the development of a knowledge-based system in the domain of steel bridge fabrication errors using both rule-based reasoning (RBR) and case-based reasoning (CBR). Fabrication error Indexed and Solutions (FIXS) was developed to combine the benefits of two previous research projects: 1) the rule-based Bridge Fabrication error solution eXpert system (BFX), and 2) its case-based counterpart (CB-BFX).

Errors that occur during the fabrication of steel bridge members can have a costly effect on the performance of a bridge if not repaired properly. FIXS is an effort to provide guidance to the bridge engineer responsible for cost effective solutions in a time sensitive manner.

FIXS is implemented in the programming language PROLOG and runs in the Windows environment as a stand-alone application. RBR facilities are provided by the expert system shell MESS (Modest Expert System Shell). Similarly, CBR functions are provided by the simple case-based reasoner shell SCBR (Simple Case Based Reasoning).

The application has been designed for addition of new domain knowledge. The addition of new and updated knowledge allows the application to keep pace with changes in the steel bridge design industry and the methods of repairing errors.

ACKNOWLEDGEMENTS

Support for this project was provided, in part, by the Kansas Department of Transportation and KTRAN Project No. KU-98-8. Additional funding was provided by the National Steel Bridge Alliance and the MidAmerica Transportation Center. Some computer resources were provided by DesignLab, NSF CDA-9401021.

Special thanks to Dr. Lindsey Spratt who provided his expert system shell, MESS, which provided the application backbone and made this project possible.

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1 INTRODUCTION & BACKGROUND

1.1 PROBLEM STATEMENT

Errors that occur during the fabrication of steel bridge members can have a deleterious effect on the performance of a bridge if not repaired properly (Bocox and Roddis 1996). Improper repair solutions can lead to costly repair work and/or reduced performance of the bridge assembly. A database of corrective actions can provide guidance to the bridge engineer responsible for corrective measures. The database can provide a list of ranked alternative solutions to be considered which ultimately shortens the solution development cycle. When used by several state DOTs within a geographical region, the database can provide standardized solution procedures thereby reducing the uncertainty of area fabricators which results in a reduction of costs passed back to the DOT.

The primary goal of this research was to develop a knowledge-based system using both rule-based reasoning (RBR) and case-based reasoning (CBR) targeted to operate in the domain of steel bridge fabrication errors. Previous work in this area included the rule-based expert system, Bridge Fabrication error solution eXpert system (BFX) (Roddis and Hess 1994; Melhem, Roddis, Nagaraja, and Hess 1996), and its case-based counterpart (CB-BFX) (Bocox and Roddis 1996; Roddis and Bocox 1997). Previous KTRAN projects on BFX are documented in Hess, Roddis, Nagaraja, Melhem, and Moran (1994) and Melhem, Moran, Roddis, and Bocox (1996). The rule-based BFX performed well in operation at KDOT (Roddis, Hess, Melhem, and Nagaraja 1995; Roddis and Hess 1995). The successful implementation of the rule-based BFX lead to the development of CB-BFX to investigate the feasibility of a case-based approach in steel bridge fabrication errors. It was found that the case-based approach provided useful

guidance for fabrication error solutions in situations when BFX did not. Likewise, BFX provides solutions in situations when CB-BFX does not. A combined system incorporating both rule-based and case-based reasoning was desired to combine the benefits of both BFX and CB-BFX. This project develops the application Fabrication error Indexed eXamples and Solutions (FIXS), a knowledge-based system operating in the domain of steel bridge fabrication errors incorporating both RBR and CBR.

1.2 Project Objectives

The objectives of this project are to:

1. Combine rule-based reasoning and case-based reasoning methods to gain increased performance over BFX or CB-BFX alone.
2. Provide an application that may be distributed to several state DOTs.
3. Provide an application with domain knowledge that can be easily updated as new information becomes available.

Objective 1 will be accomplished using the programming language PROLOG in conjunction with the program named MESS (Modest Expert System Shell) (Spratt 1998). MESS is an expert system shell written in PROLOG which provides general rule-based reasoning services. Case-based reasoning services will be provided by a custom written CBR shell. SCBR (Simple Case-Based Reasoning) is written in PROLOG and integrates with MESS.

Objective 2 will be accomplished by producing a stand-alone Windows application which can be readily used by many state DOTs. The stand-alone application can be installed on multiple machines royalty free thus making distribution simple and reducing the out of pocket software costs for DOTs.

Finally, to accomplish objective 3, the knowledge of fabrication errors will be kept modular and separated from the application's front-end or Graphical User Interface (GUI). To update or expand the knowledge base, the user need only upgrade the knowledge files and not the entire application. This will simplify the process of keeping an up-to-date database of solutions.

2 SOFTWARE DEVELOPMENT

2.1 DEVELOPMENT TOOL CHOICE

Software development of the combined rule-based and case-based application began with a search for commercially available off-the-shelf development tools. The required characteristics of the development tool needed to include the ability to use RBR and CBR in one package. DOT end users of the application require it to execute on Windows based operating systems, specifically Windows 3.1, Windows 95 and Windows NT. Finally, desired characteristics of the development tool required a robust GUI development set and the ability to distribute the software royalty free. With these requirements to satisfy, no suitable commercial development tool was found. Focus on the development tool turned toward a custom written development tool using an existing expert system shell which could be modified to meet the requirements.

PROLOG was chosen as the programming language since it readily supports the development of RBR and CBR mechanisms. LPA WIN-PROLOG (Logic Programming Associates Ltd 1997) was the specific PROLOG compiler used for the application. WIN-PROLOG supports all of the Windows operating systems required for deployment of the application to end users. Applications can be delivered royalty free in a stand-alone form simplifying software distribution.

An expert system shell written in the programming language PROLOG named MESS (Modest Expert System Shell) was chosen to provide the rule-based tools for the application. The developer of this tool was available to make modifications to the shell when needed such that it could be tailored to the requirements of the application. A custom CBR shell named Simple Case Based Reasoning (SCBR) was also written in PROLOG. For the initial version of

FIXS the focus was on providing a functional application using both RBR and CBR therefore, a complicated case-based reasoner was not required. Later versions of the application may use a more polished case-based reasoner providing more functionality. The matching approach of SCBR discussed in section 2.3.3 of this report.

2.2 Design Considerations

Development of FIXS began with a review of BFX to determine what worked well and what needed improvement. It was found from BFX that dialog boxes organized to collect multiple items of data grouped by similar topic was desirable. This allows for more expedient entry of problem data rather than asking the user for each piece of information one at a time as needed. The major problem with this approach is that with a dialog box containing multiple items of data to input, the user has no way of determining what piece or possibly pieces of information are most important or needed. This was a shortcoming of BFX which needed to be rectified with FIXS. BFX also lacked the ability to tell the user why it needed a particular piece of information. The ability of a knowledge-based system to explain its actions is important since it allows the user to follow the application's chain of reasoning. Likewise, once a solution has been found, the application needs the ability to explain how the solution was located so that the user can confirm that the solution is indeed valid. FIXS was designed to provide these explanation mechanisms to the user. Finally, the documentation and reporting mechanism of BFX was awkward and in need of improvement. Users need the ability to print hardcopy documents of solutions and results obtained from FIXS. Reporting facilities were provided in FIXS to address this problem.

CB-BFX was a pilot application used to investigate the feasibility of CBR in this project's domain. CB-BFX also investigated how it could provide guidance in conjunction with BFX. Since CB-BFX was used for research purposes only, the user interface of the application was not designed with a user friendly GUI so one needed to be designed. Integrating RBR and CBR proved to be somewhat challenging when considering the method of getting problem data to each type of reasoner. While many pieces of information are common among RBR and CBR, the amount of data needed to perform each differs. RBR needs only enough data to satisfy a particular rule while CBR needs as much information as possible to do a search and comparison of case data. A logical method of gathering the data was needed so as not to confuse the application's user.

2.3 IMPLEMENTATION

2.3.1 User Interface

Implementation of FIXS started with design of the GUI. GUI development focused on providing a user friendly environment that behaved in a manner familiar to users. The development also focused on eliminating all references to the topic of "Expert System" or "Knowledge System." Naming an application an expert or knowledge system tends to alter the way users look and think about a software program. The name Fabrication error Indexed eXamples and Solutions (FIXS) was chosen since this conveys a more database like application, giving potential users a better idea of what to expect in program capabilities.

Two main tools, Find Solutions and Browse Solutions, are available to the user for locating an error solution. Find Solutions uses RBR and CBR mechanisms for a guided approach to solution location. This provides a method of locating rule-based solutions and case-

based solutions that best match the current problem at hand. Results of this search are ranked according to their similarity to the problem being solved. Browse Solutions provides the user with a complete listing of all error solutions for a given error type. This provides a method for the user to see what information is stored within the knowledge base and also allows the user to manually search for solutions if desired.

During a Find Solutions session, several dialog boxes requesting multiple items of data are presented to the user regarding the fabrication error being solved. A method of providing guidance to the user as to which piece or pieces of data are required to be entered into any one particular dialog box was developed. A "highlight" was designed to display next to the dialog control item needing a response from the user as shown in figure 1. Generally, this piece of information is required to be provided by the user before continuing. Data may still be entered into other controls within the dialog box, not just the highlighted control. The highlight is merely a guide to the user pointing to the data required.

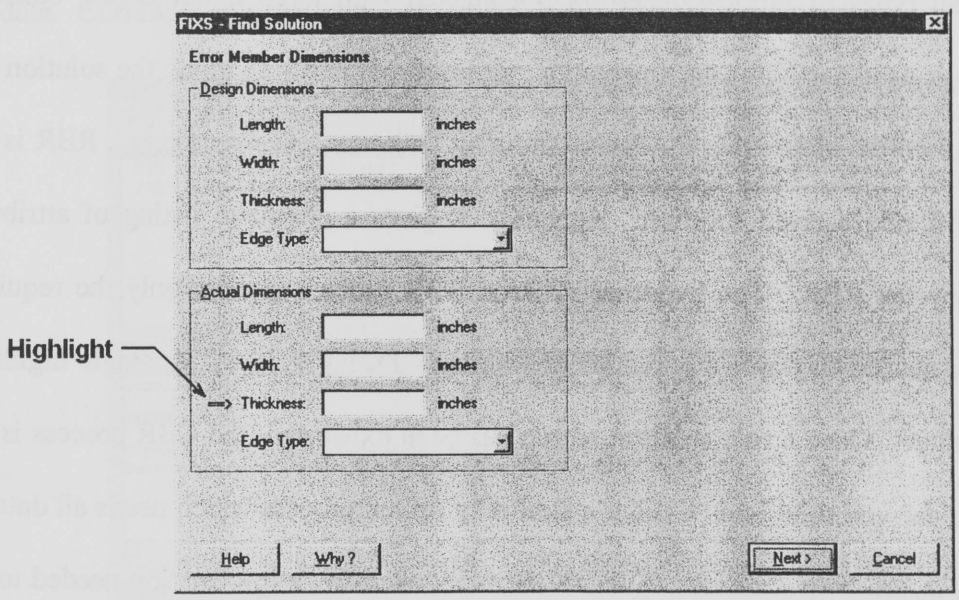

Figure 1 Query Dialog with Single Highlight

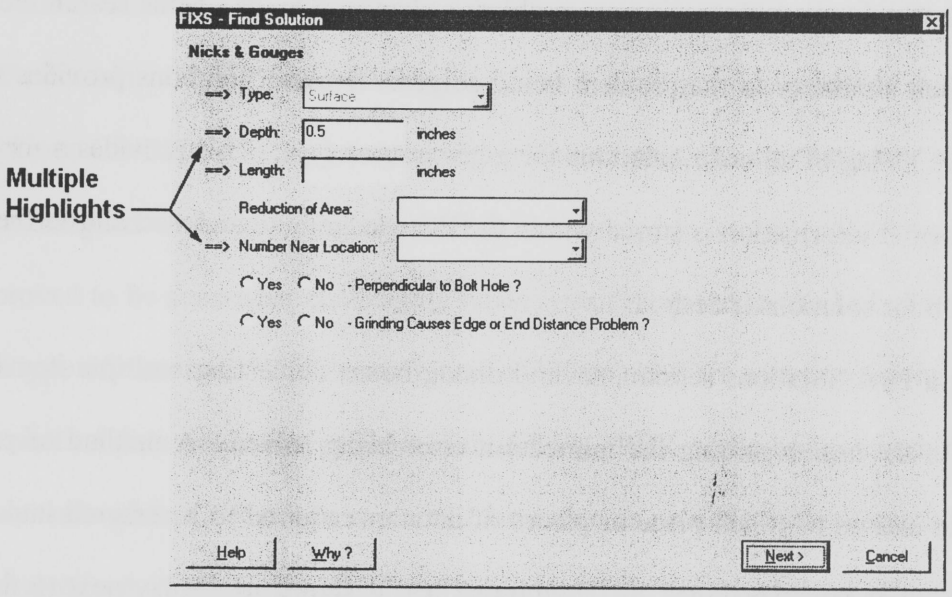

Figure 2 Query Dialog with Multiple Highlights

As stated earlier, collecting data for both RBR and CBR has difficulties concerned with the amount of data needed at a given time for each search method. The solution to this problem requires the following sequence of events to occur during a Find Solutions query. First, data common to all types of fabrication errors is collected with three initial dialog boxes. This common data is used partly for documentation purposes and partly to guide the solution location process (i.e. selection of error type). Once all common data has been collected, RBR is invoked to search for a rule derived solution. Appendix A gives a complete listing of attributes and values used by the RBR. The hypothesis driven RBR process gathers only the required data from the user needed to prove any particular solution. Dialog boxes with single highlights are used at this stage. Once a rule solution search has been exhausted, the CBR process is invoked to locate case derived solutions. CBR is a similarity driven process which needs all data prior to performing a match between cases. When CBR is invoked some information needed to locate a case solution has already been input by the user during the RBR process. The remaining information needed to perform a case search is simply collected by displaying dialog boxes with

multiple highlights as shown in figure 2. It is important to note that not all highlighted or requested data needs to be provided by the user for the CBR process to succeed. Some of the data requested by the case-based reasoner is not applicable to the current fabrication error being solved. The user makes the decision as to what data is applicable based on the context of the problem. Data that is not applicable is simply not provided by either not selecting or not typing a response depending on the type of dialog control in question.

At the end of a Find Solutions search, if any solutions have been located either by RBR or CBR, a Solution Results dialog box is displayed. A list of solutions ranked by a similarity metric is given along with their respective repair procedures (figure 3). The user has the option of displaying more detailed information for a solution with a Solution Detail dialog box. The solution detail dialog box gives more specific information such as detail graphics associated with the solution. Reports can also be generated by selecting the Report button. Reports are written to a text file containing all located solutions and solution procedures along with a listing of all input data. Currently, reports cannot be printed directly to a system printer.

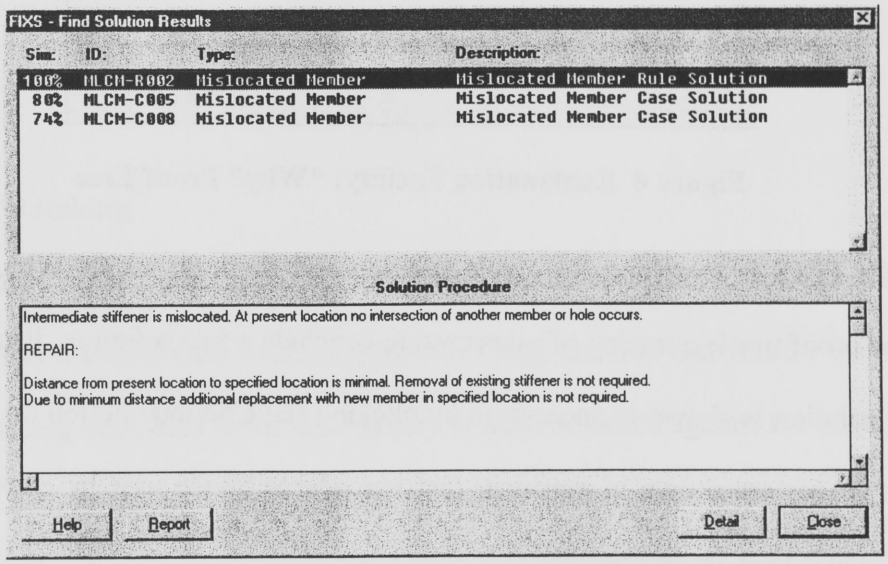

Figure 3 Solution Results Dialog

2.3.2 Explanation Facility

The user interface supports use of an explanation facility. During a Find Solutions search, the user has the option of asking the application why a particular piece of information is being requested. The user may believe that a requested piece of information does not fit the context of the problem being solved. Selecting the Why button from the Find Solutions dialog box provides either a proof tree (figure 4) for finding a rule solution or a list of features (figure 5) required to locate a case solution of given error type.

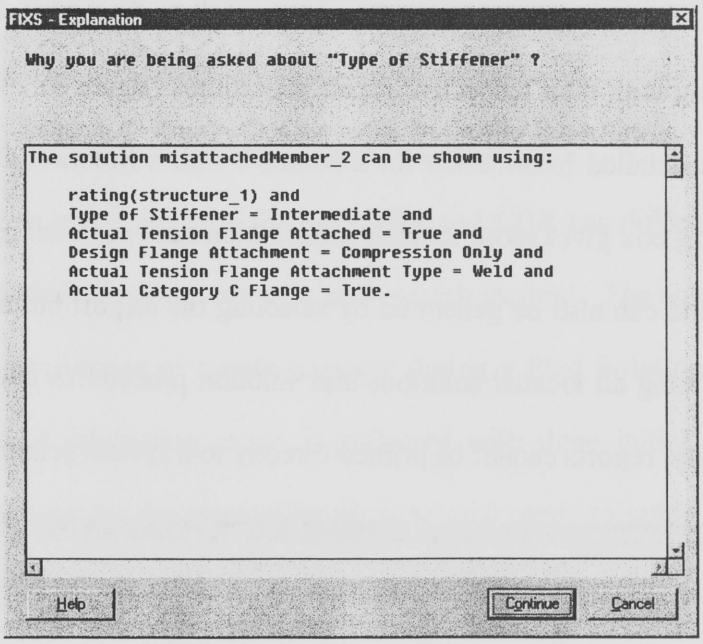

Figure 4 Explanation Facility: "Why" Proof Tree

While FIXS is searching for a rule solution and the user selects Why, a proof tree is shown. The proof tree is a tracing of rules used to conclude a rule solution. Each rule needed to conclude a solution is shown in succession by clicking the Continue button on the Explanation dialog box. Rules are shown in a manner that is readable by the user by converting predicate names and values to short descriptions.

While FIXS is gathering data for a case solution search, the explanation facility provides the user with a list of features used to describe the current error type. Each feature predicate is translated to a short description in the same manner as rule predicates are translated. The list simply allows the user to see what information is being collected to build an input case for searching the case library.

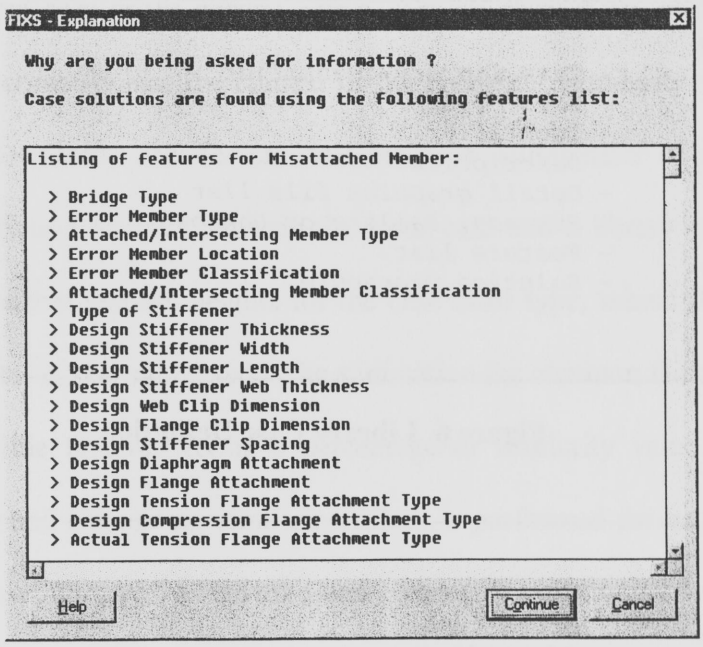

Figure 5 Explanation Facility: "Why" List of Features

2.3.3 Case Matching

As stated earlier, a simple CBR matching process was desired for the initial version of FIXS. SCBR is a simple case matching process using features and feature weights. A list of features describing each case in the case library is used to match against the same features of an input case. Cases in the case library consist of header information, a feature list, and a solution procedure as defined in figure 6. An input case is similar to a library case but lacks some of the header information and the solution procedure (figure 7). Feature weights are used in the

matching process to describe the importance of each feature in the feature list. Weights are on a scale of 0 to 1 with 1 being most important. Features and feature weights were taken directly from CB-BFX with little modification except for feature naming conventions. Appendix B gives a complete listing of features and feature weights for each error type. To the extent possible, the RBR attributes correspond with the CBR features.

```
caseSolution(
  Solution,        - Case library identifier
  Type,            - Error type
  Id,              - Identifier
  Description,     - Description
  Details,         - Detail graphics file list
  Status,          - Success, Failure or Unknown
  Features,        - Feature list
  Repair           - Solution procedure
).
```

Figure 6 Library Case Definition

```
caseInput(
  Solution,        - Case library identifier
  Type,            - Error type
  Id,              - Identifier
  Description,     - Description
  Status,          - Success, Failure or Unknown
  Features,        - Feature list
).
```

Figure 7 Input Case Definition

Before matching can occur, an input case must be built from the data provided by the user during a Find Solutions session. It is important to note that not all of the features for the problem error type will have data supplied by the user. As stated earlier, the user can elect to supply information for a given request based on the context of the problem. Features without input data are dropped from the feature list of the input case.

The case matching process works by considering those features which are common between the input case and each case in the case library that has the given error type. Case matching is thus done only in the subpart of the case library exactly matching the given error type. Considering common features means that the feature for the input case matches exactly to the respective feature in the library case. Features not defined due to lack of input data or library data in either the input case or the current library case are thrown out of the matching process since these would incorrectly bias the context of the problem. Similarity values are calculated for each library case using the feature weights. A summation of all feature weights corresponding to common features between the input case and a library case is calculated. A summation of all possible feature weights for the case error type, minus those features thrown out due to lack of data, is also calculated. The summation for common features is divided by the summation for possible features giving a percentage or similarity value (Equation 1). The process of matching and calculating similarity values is performed for each case for the given error type in the case library. A list of library cases is constructed based on a minimum acceptable similarity value and a maximum number of cases to return. The minimum similarity value sets a cutoff for how good of a match is desired while the maximum number to return restricts the number of cases. Each of these values is settable by the user within the user preferences of the application.

$$\frac{\sum \text{Common Feature Weights}}{\sum \text{Possible Feature Weights}} = \text{Similarity (\%)}$$

$\sum$ Common Feature Weights - *All feature weights corresponding to matching features between the input case an a library case.*

$\sum$ Possible Feature Weights - *All feature weights for given error type less all features weights not included due to lack of input or library data.*

Equation 1 Similarity Value Calculation

2.3.4 Knowledge Base

The types of fabrication errors which FIXS currently has domain knowledge of are shown in figure 8. Error types are divided into the four categories of Tolerance, Drilling & Punching, Cutting, and Lamination. Each of the four categories is further divided into specific error types giving a taxonomy of common errors.

Rule-based knowledge from BFX along with case-based knowledge from CB-BFX was used to develop the initial knowledge base for FIXS. The knowledge from each source was adapted to the syntax required by FIXS. The original BFX rules where written in Production Rule Language (Information Builders, Inc. 1993) which were converted to a similar format for use with MESS. CB-BFX cases where written as LISP structures which were converted to PROLOG syntax for use with SCBR. An example of each conversion is shown in Appendix C.

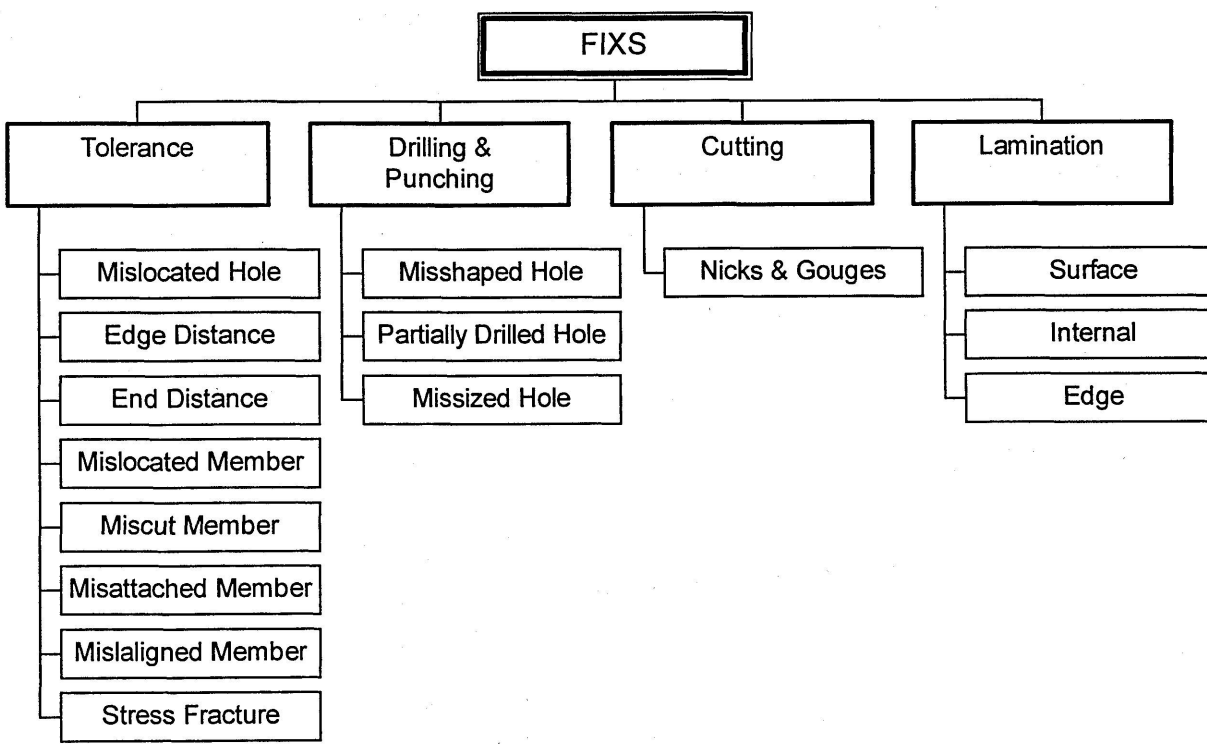

Figure 8 Fabrication Error Types

The knowledge base currently contains 121 rule solutions and 112 case solutions. Approximately 350 rules are used to search for rule solutions. Additional data was solicited and collected but was not added to the knowledge base during this phase of the project. Later project phases will increase the size of the knowledge base to enhance the performance in areas of knowledge deficiency. Figures 9 & 10 shows the distribution of rule and case knowledge for each error type as implemented in the initial version of FIXS.

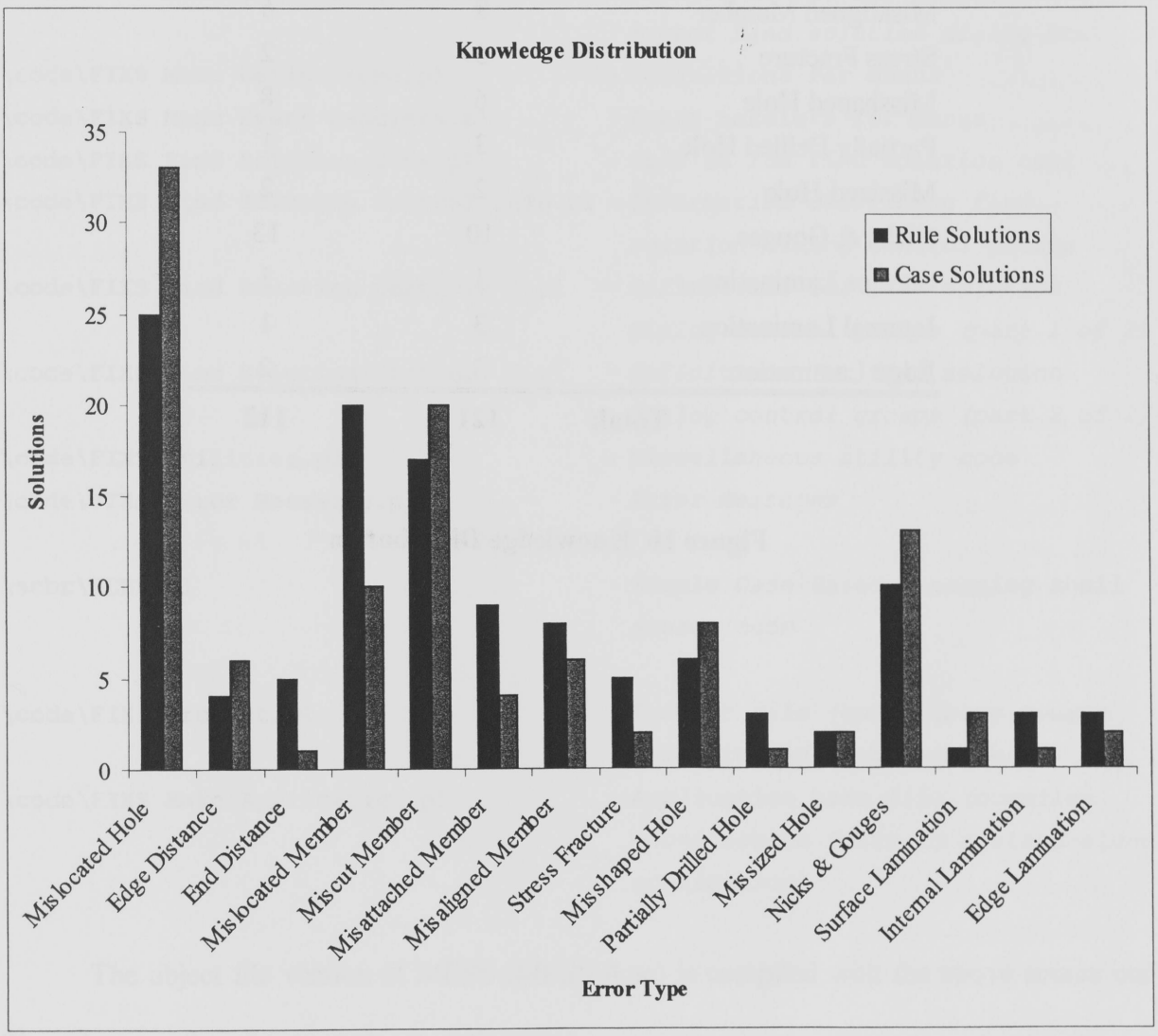

Figure 9 Knowledge Distribution

Error Type	Rule Solutions	Case Solutions
Mislocated Hole	25	33
Edge Distance	4	6
End Distance	5	1
Mislocated Member	20	10
Miscut Member	17	20
Misattached Member	9	4
Misaligned Member	8	6
Stress Fracture	5	2
Misshaped Hole	6	8
Partially Drilled Hole	3	1
Missized Hole	2	2
Nicks & Gouges	10	13
Surface Lamination	1	3
Internal Lamination	3	1
Edge Lamination	3	2
Total:	**121**	**112**

Figure 10 Knowledge Distribution

2.3.5 Development Files

Source code for the implementation of FIXS was divided into several files for development and maintenance purposes. The following list provides descriptions for each source code file written to create FIXS:

```
\code\FIXS Main.pl                          - Startup and cleanup code
\code\FIXS Dialog Definitions.pl            - Definitions for dialog boxes
\code\FIXS Dialog Event Handlers.pl         - Event handlers for dialog boxes
\code\FIXS Dialog Handling Code.pl          - Code to manage all dialog boxes
                                              expect find solution dialog box
\code\FIXS Menu Definitions.pl              - Definitions for menus
\code\FIXS Menu Event Handlers.pl           - Event handlers for menus
\code\FIXS Find Solution Code.pl            - Code to run find solution tool
\code\FIXS Find Solution Control Info.pl - Information describing find
                                              solution dialog control groups
\code\FIXS Find Solution Controls 1.pl      - Definitions for find solution
                                              dialog control groups (part 1 of 2)
\code\FIXS Find Solution Controls 2.pl      - Definitions for find solution
                                              dialog control groups (part 2 of 2)
\code\FIXS Utilities.pl                     - Miscellaneous utility code
\code\FIXS Error Messages.pl                - Error Messages

\scbr\SCBR.pl                               - Simple Case-Based Reasoning shell
                                              source code

\code\FIXS Project.pl                       - Project file (opens above source
                                              files for editing purposes)
\code\FIXS Make Application.pl              - Application make file (compiles
                                              above source files to a stand-alone
                                              application)
```

The object file version of MESS (MESS 4.pc) is compiled with the above source code files when creating the stand-alone application.

As stated earlier, changes to the knowledge-base requires an upgrade to the knowledge files only and not the entire set of application files. The following is a listing with descriptions of all knowledge-base related source files:

\knb\knbreden.pl	- *AASHTO edge/end distance rules*
\knb\knbredgd.pl	- *Edge Distance rules*
\knb\knbredgl.pl	- *Edge Lamination rules*
\knb\knbrendd.pl	- *End Distance rules*
\knb\knbrintl.pl	- *Internal Lamination rules*
\knb\knbrmalm.pl	- *Misaligned Member rules*
\knb\knbrmatm.pl	- *Misattached Member rules*
\knb\knbrmctm.pl	- *Miscut Member rules*
\knb\knbrmlch.pl	- *Mislocated Hole rules*
\knb\knbrmlcm.pl	- *Mislocated Member rules*
\knb\knbrmsph.pl	- *Misshaped Hole rules*
\knb\knbrmszh.pl	- *Missized Hole rules*
\knb\knbrnags.pl	- *Nick/Gouge rules*
\knb\knbrpdrh.pl	- *Partially Drilled Hole rules*
\knb\knbrsfrc.pl	- *Stress Fracture rules*
\knb\knbrsurl.pl	- *Surface Lamination rules*
\knb\knbcedgd.pl	- *Edge Distance cases*
\knb\knbcedgl.pl	- *Edge Lamination cases*
\knb\knbcendd.pl	- *End Distance cases*
\knb\knbcintl.pl	- *Internal Lamination cases*
\knb\knbcmalm.pl	- *Misaligned Member cases*
\knb\knbcmatm.pl	- *Misattached Member cases*
\knb\knbcmctm.pl	- *Miscut Member cases*
\knb\knbcmlch.pl	- *Mislocated Hole cases*
\knb\knbcmlcm.pl	- *Mislocated Member cases*
\knb\knbcmsph.pl	- *Misshaped Hole cases*
\knb\knbcmszh.pl	- *Missized Hole cases*
\knb\knbcnags.pl	- *Nick/Gouge cases*
\knb\knbcpdrh.pl	- *Partially Drilled Hole cases*
\knb\knbcsfrc.pl	- *Stress Fracture cases*
\knb\knbcsurl.pl	- *Surface Lamination cases*

Several utility predicates used to integrate but maintain separation of knowledge and application are defined in two knowledge utility files:

`\code\FIXS Knowledge Utilities 1.pl`	- *Knowledge utilities (part 1 of 2)*
`\code\FIXS Knowledge Utilities 2.pl`	- *Knowledge utilities (part 2 of 2)*
`\code\FIXS Make Knowledge.pl`	- *Knowledge make file (compiles above two knowledge utility files to a single object file: knbutils.pc)*

Source files for the online help facility were developed with the following files:

`\help\fixs.hpj`	- *Help project file defining context ids, etc.*
`\help\fixs.rtf`	- *Main help source file*
`\help\fsdhelp.rtf`	- *Find solution help source file*

2.3.6 Application Files

The stand-alone application has the following directory and file structure when installed:

\fixs\fixs.exe	- *WIN-PROLOG executable*
\fixs\fixs.ovl	- *Application overlay*
\fixs\fixs.dll	- *WIN-PROLOG dynamic link library*
\fixs\fixs.ini	- *Initialization file*
\fixs\fixs.bmp	- *Logo bitmap*
\fixs\fixs.hlp	- *Help file*
\fixs\knb\knbr????.pl	- *All rule knowledge source files (16) as listed above under the Development Files section*
\fixs\knb\knbc????.pl	- *All case knowledge source files (15) as listed above under the Development Files section*
\fixs\knb\knbutils.pc	- *Knowledge utilities object file*
\fixs\bmp\fixs-na.bmp	- *Default detail graphic bitmap used when no detail graphic(s) is specified for a given rule or case solution*
\fixs\bmp*.bmp	- *Detail graphic bitmaps for rule and case solutions*

3 CONCLUSIONS & FUTURE WORK

3.1 CONCLUSIONS

Designing the GUI to support both RBR and CBR proved to be a somewhat challenging task. Sequencing the Find Solutions tool to first collect documentation data and data common to all types of errors, followed by collection of data for RBR and CBR, proved to be an appropriate method. This sequencing of data input flows in a logical fashion so that users are not confused by the data input process. This sequencing method also helps to minimize the amount of data entered by the user by gathering hypothesis-driven RBR data prior to the data- or similarity-driven CBR data.

Methods developed for using dialog box "highlights" directing users to enter the most important data proved to be very successful. Only the data pointed to by the highlight needs to be provided, although more can be provided if the user desires. This corrected a shortcoming of BFX that hindered its operational use.

Although it has not been tested in operation, addition of the explanation facility should provide users with a more secure feeling about how FIXS is locating solutions. The explanation facility helps to eliminate the "black box" analogy that is often used to describe mechanisms that are not completely understood, by allowing the user to see what is occurring.

Documentation of results obtained from a Find Solutions session have been improved to allow easy generation of reports. Although the method of generating reports does not allow printing directly to a system printer, it is a marked improvement over past methods.

Combination of RBR and CBR has been successfully implemented with FIXS although validation and testing is still required to determine the extent of this success.

3.2 FUTURE WORK

The mechanism to search for solutions has been implemented. Additional cases are now required to create a knowledge base that covers the full spectrum of error types more completely. This will require additional knowledge for many of the error types currently addressed. With a reasonably complete knowledge base in place, the application can then expand its knowledge through the addition of new cases created during its operation use.

Additional knowledge as well as changes and additions to the front-end and knowledge-base are being continued. Items such as adding an error type specifically for stiffener errors and providing a formal means to provide updated knowledge to the user are being considered. Changes to the SCBR shell are also being considered to improve performance of the CBR portion of FIXS. Modifications that may occur to upgrade the SCBR shell include providing functions to manage the case-base and a more robust matching process.

Like its successful predecessors, FIXS has the ability to provide prompt and cost effective solutions for fabrication errors to the bridge engineer. While the immediate benefit of FIXS may be measured as its ability to provide solutions, it also has the long range ability to provide a service of preventing fabrication errors. Cataloging the types of errors that typically occur during the manufacture of steel bridge components can provide a means to determine what errors occur most commonly for a particular type of design or member. Those responsible for design of steel bridges can use this information to produce designs that minimize the occurrence of these errors. Fabricators can use this information to prevent the occurrence of such errors, improving the quality of bridge member fabrication, directly benefiting both fabricators and DOTs

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APPENDIX A – RULE ATTRIBUTES / FEATURES

CLASS	ATTRIBUTE / FEATURE	INPUT PREDICATE	POSSIBLE VALUES			
Error Classification	*Tolerance*	errorClassification	mislocated hole	edge distance	end distance	mislocated member
			misaligned member	miscut member	misattached member	stress fracture
	Cutting		nicks & gouges			
	Drilling / Punching		misshaped hole	missized hole	partially drilled hole	
	Lamination		internal	edge	surface	
Error Stage	*Error member attached?*	errorStageErrorMemberAttached	yes	no		
	Stage error occurred		layout	fitup	blocking / laydown	field erection
	Stage error found		layout	fitup	blocking / laydown	field erection
Structure	*Bridge type*	bridgeType	plate girder	rolled	box girder	truss
			combination	other		
	End supports		simple	continuous	cantilever	balanced cantilever
	Intermediate supports		simple	continuous	cantilever	balanced cantilever
	Number of spans					
	Error member type	errorMemberType	plate girder	box girder	capbeam	splice plate
			bearing stiffener	intermediate stiffener	filler plate	diaphragm or brace
			k-connection	flange plate	web plate	rocker
	Error member location	errorMemberLocation	compression flange	web	tension flange	splice
			stiffener attachment	bearing	gusset plate	bolted connection
	Error member classification	errorMemberClass	fracture critical	primary	secondary	unknown
	Attached or Intersecting member type	attachMemberType	plate girder	box girder	capbeam	splice plate
			bearing stiffener	intermediate stiffener	filler plate	diaphragm or brace
			k-connection	flange plate	web plate	rocker
	Attached or Intersecting member classification	attachMemberClass	fracture critical	primary	secondary	unknown
Error Member Dimensions	*Specified length*	errorMemberDesignLength				
	Specified width	errorMemberDesignWidth				
	Specified thickness					
	Specified edge type		flame cut	sheared	rolled	planed
	Actual length	errorMemberActualLength				
	Actual width	errorMemberActualWidth				
	Actual thickness	errorMemberActualThickness				
	Actual edge type	errorMemberActualEdgeType	flame cut	sheared	rolled	planed
Attached or Intersecting Member Dimensions	*Specified length*					
	Specified width					
	Specified thickness					
	Specified edge type		flame cut	sheared	rolled	planed
	Actual length					
	Actual width					
	Actual thickness					
	Actual edge type		flame cut	sheared	rolled	planed

CLASS	ATTRIBUTE / FEATURE	INPUT PREDICATE	POSSIBLE VALUES			
Hole Details	*Hole type*	holeDetailsType	circular	short slotted	long slotted	egg shaped
			irregular shaped	oversize	other	
	Boring Procedure	holeDetailsHoleBoringProcedure	drilled	sub drilled	punched	sub punched
			drilled from solid	reamed	template	
	Number with errors	holeDetailsNumberWithErrors				
	Number in grouping	holeDetailsNumberInGrouping				
	Joint slip critical?	holeDetailsJointSlipCritical	yes	no		
	Slots at correct slope?	holeDetailsSlotsAtCorrectSlope	yes	no		
	Holes meet edge & end distance specification?	holeDetailsEdgeEndDistanceSpecification	yes	no		
	Specified bolt diameter					
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter				
	Specified longitudinal hole spacing					
	Specified transverse hole spacing					
	Actual bolt diameter	holeDetailsActualBoltDiameter				
	Actual hole diameter					
	Actual longitudinal hole spacing	holeDetailsActualLongHoleSpacing				
	Actual transverse hole spacing	holeDetailsActualTransverseHoleSpacing				
	Actual elongation distance					
	Partially drilled hole(s) ?		yes	no		
	Partially drilled hole depth	holeDetailsPartDrilledHoleDepth				
	Partially drilled hole diameter					
	Partially drilled hole coverage of specified hole (%)					
Hole Distance	*Distance from error member*					
	Distance from intersecting member	holeDistanceFromIntersectingMember				
	Distance from member edge	holeDistanceFromEdge				
	Distance from member end	holeDistanceFromEnd				
Mislocated Hole	*Distance to correct location*	mislocatedHoleDistanceCorrectLocation				
	Hole placed in wrong flange?	mislocatedHoleIncorrectFlange	yes	no		
	Reinforcing steel hole(s)?	mislocatedHoleReinforcingSteelHole	yes	no		
	Error due to additional row bored?	mislocatedHoleAdditionalRowHolesDrilled	yes	no		
	Holes meet edge & end distance specification?	mislocatedHoleEdgeEndDistanceSpecification	yes	no		
	Intersection at current location?	mislocatedHoleIntersectionCurrentPosition	yes	no		
	Specified hole pattern bored correctly?	mislocatedHoleSpecifiedHolePatternCorrect	yes	no		
	Hole pattern interferes with specified pattern?	mislocatedHoleInterfereWithSpecifiedPattern	yes	no		
	Intersection with additional bolt line?	mislocatedHoleIntersectionNewPosition	yes	no		
Mislocated Member	*Intersection occurs?*	mislocatedMemberIntersection	yes	no		
	Intersected item	mislocatedMemberIntersectedItem	hole	splice plate	attached member	other
	Inverted placement?	mislocatedMemberInvertedPlacement	yes	no		
	Distance to correct location	mislocatedMemberDistanceCorrectLocation				

CLASS	ATTRIBUTE / FEATURE	INPUT PREDICATE	POSSIBLE VALUES			
Stiffener	*Stiffener type*	stiffenerType	bearing	intermediate	longitudinal	
	Specified thickness					
	Specified length					
	Specified width					
	Specified web thickness					
	Specified clip dimension on web					
	Specified clip dimension on flange					
	Specified spacing between stiffeners					
	Specified diaphragm or brace attachment?	stiffenerSpecifiedDiaphragmAttachment	yes	no		
	Specified flange attachment	stiffenerSpecifiedFlangeAttachment	tension only	compression only	tension & compression	
	Specified tension flange attachment type	stiffenerSpecifiedTensionFlangeAttachmentType	weld	bolted angle	bolted plate	
	Specified compression flange attachment type	stiffenerSpecifiedCompFlangeAttachmentType	weld	bolted angle	bolted plate	
	Actual category 'C' qualified?	stiffenerActualCategoryCFlange	yes	no		
	Actual tension flange clipped?		yes	no		
	Actual compression flange clipped?		yes	no		
	Actual tension flange attached?	stiffenerActualTensionFlangeAttached	yes	no		
	Actual compression flange attached?	stiffenerActualCompFlangeAttached	yes	no		
	Actual tension flange attachment type	stiffenerActualTensionFlangeAttachmentType	weld	bolted angle	bolted plate	
	Actual compression flange attachment type	stiffenerActualCompFlangeAttachmentType	weld	bolted angle	bolted plate	
	Actual bottom within middle 50% of sole plate?	stiffenerActualMiddleOfSolePlate	yes	no		
	Actual out of plumbness (%)	stiffenerActualPlumbness				
Miscut Member	*Miscut occurs at*	miscutMemberErrorOccursAt	end	center	entire member	
	Specified sweep	miscutMemberSpecifiedSweep				
	Actual sweep	miscutMemberActualSweep				
	Specified clipped?	miscutMemberSpecifiedClipped	yes	no		
	Actual clipped?	miscutMemberActualClipped	yes	no		
	Clipped dimension correct?	miscutMemberClippedDimensionsCorrect	yes	no		
Stress	*Error member stress type*	stressErrorMemberType	tension	compression	unknown	
	Error member stress level	stressErrorMemberLevel	high	medium	low	unknown
	Attached or Intersecting member stress level		high	medium	low	unknown
	Fatigue concerns	stressFatigueConcerns	high	medium	low	unknown
	Stress fracture(s) ?	stressFractures	yes	no		
	Maximum gap between fracture(s)	stressMaxGap				
	Number of fractures at location		excessive	moderate	few	single
	Angle of bend at fracture(s)					
Lamination	*Surface lamination type*	laminationSurfaceType	rolling	beer tabs		
	Mapping / Documentation		complete	not complete	in progress	
	Test required		RT	UT	dye penetration	MT
			visual	linear gauge	other	
	Lamination area w.r.t. plate area		small	medium	large	
	Length of deformity					
	Width of deformity					

CLASS	ATTRIBUTE / FEATURE	INPUT PREDICATE	POSSIBLE VALUES			
Nicks & Gouges	*Nick or Gouge type*	nickGougeType	surface	edge	end	cope
			hole			
	Depth	nickGougeDepth				
	Length					
	Reduction of area		excessive	moderate	small	very small
	Number near location		excessive	moderate	few	single
	Perpendicular to bolt hole?		yes	no		
	Grinding causes edge or end distance problem?	nickGougeGrindEdgeEndDistance	yes	no		
Surface Alignment	*Full surface contact?*	surfaceFullSurfaceContact	yes	no		
	Fill plate specified?	surfaceFillPlate	yes	no		
	Heat procedure approved?	surfaceHeatProcedure	yes	no		
	Contact spacing	surfaceContactSpacing				
	Percent contact	surfacePercentContact				
	Fill plate thickness	surfaceFillPlateThickness				
Fabrication Status	*Detail extensiveness*		large	medium	small	
	Connection details		completed	in progress	to be made	
	Curvature		large	medium	small	
	Camber		large	medium	small	
	Percent complete					
	Ease of replacement		hard	medium	easy	
	Curvature complete?		yes	no		
	Camber complete?		yes	no		
Project	*Type*		fast track	regular speed		
Inspection	*Experience*		good	medium	poor	
	Examination procedures		RT	UT	dye penetration	MT
			visual	linear gauge	other	
Error	*Proximity from intersecting member*		very close	close	medium	far
	Degree		large	medium	low	
Paint	*Paint damage*		undamaged	medium	damaged	
Fabrication	*Fabrication experience*		good	medium	poor	
	Quality control program		good	medium	poor	
	Fabrication equipment		good	medium	poor	
	Final Products		good	medium	poor	

APPENDIX B – CASE ATTRIBUTES / FEATURES

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Edge Distance (EDGD)	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.7
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Error member actual edge type	errorMemberActualEdgeType	0.8
	Attached or Intersecting member actual edge type	attachMemberActualEdgeType	0.4
	Hole type	holeDetailsType	0.8
	Number of holes with errors	holeDetailsNumberWithErrors	0.5
	Number of holes in grouping	holeDetailsNumberInGrouping	0.5
	Actual bolt diameter	holeDetailsActualBoltDiameter	0.5
	Actual hole diameter	holeDetailsActualHoleDiameter	0.5
	Actual longitudinal hole spacing	holeDetailsActualLongHoleSpacing	0.3
	Actual transverse hole spacing	holeDetailsActualTransverseHoleSpacing	0.3
	Specified bolt diameter	holeDetailsSpecifiedBoltDiameter	0.5
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.5
	Specified longitudinal hole spacing	holeDetailsSpecifiedLongHoleSpacing	0.3
	Specified transverse hole spacing	holeDetailsSpecifiedTransverseHoleSpacing	0.3
	Partially drilled hole(s)?	holeDetailsPartDrilledHole	0.5
	Partially drilled hole diameter	holeDetailsPartDrilledHoleDiameter	0.2
	Partially drilled hole depth	holeDetailsPartDrilledHoleDepth	0.5
	Partially drilled hole coverage of specified hole (%)	holeDetailsPartDrilledHoleCoverage	0.5
	Hole boring Procedure	holeDetailsHoleBoringProcedure	0.6
	Hole distance from intersecting member	holeDistanceFromIntersectingMember	0.3
	Hole distance from error member	holeDistanceFromErrorMember	0.3
	Hole distance from member edge	holeDistanceFromEdge	0.8
	Hole distance from member end	holeDistanceFromEnd	0.5
End Distance (ENDD)	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.7
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Error member actual edge type	errorMemberActualEdgeType	0.8
	Attached or Intersecting member actual edge type	attachMemberActualEdgeType	0.4
	Hole type	holeDetailsType	0.8
	Number of holes with errors	holeDetailsNumberWithErrors	0.5
	Number of holes in grouping	holeDetailsNumberInGrouping	0.5
	Actual bolt diameter	holeDetailsActualBoltDiameter	0.5
	Actual hole diameter	holeDetailsActualHoleDiameter	0.5
	Actual longitudinal hole spacing	holeDetailsActualLongHoleSpacing	0.3
	Actual transverse hole spacing	holeDetailsActualTransverseHoleSpacing	0.3
	Specified bolt diameter	holeDetailsSpecifiedBoltDiameter	0.5
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.5
	Specified longitudinal hole spacing	holeDetailsSpecifiedLongHoleSpacing	0.3
	Specified transverse hole spacing	holeDetailsSpecifiedTransverseHoleSpacing	0.3
	Partially drilled hole(s)?	holeDetailsPartDrilledHole	0.5
	Partially drilled hole diameter	holeDetailsPartDrilledHoleDiameter	0.2
	Partially drilled hole depth	holeDetailsPartDrilledHoleDepth	0.5
	Partially drilled hole coverage of specified hole (%)	holeDetailsPartDrilledHoleCoverage	0.5
	Hole boring Procedure	holeDetailsHoleBoringProcedure	0.6
	Hole distance from intersecting member	holeDistanceFromIntersectingMember	0.3
	Hole distance from error member	holeDistanceFromErrorMember	0.3
	Hole distance from member edge	holeDistanceFromEdge	0.5
	Hole distance from member end	holeDistanceFromEnd	0.8

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Edge Lamination ***(EDGL)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.3
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Mapping / Documentation	laminationMappingDocumentation	0.7
	Test required	laminationTestRequired	0.6
	Length of deformity	laminationLengthOfDeformity	0.5
	Width of deformity	laminationWidthOfDeformity	0.5
Internal Lamination ***(INTL)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.3
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Mapping / Documentation	laminationMappingDocumentation	0.7
	Test required	laminationTestRequired	0.6
	Length of deformity	laminationLengthOfDeformity	0.5
	Width of deformity	laminationWidthOfDeformity	0.5
Surface Lamination ***(SURL)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.3
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Surface lamination type	laminationSurfaceType	0.9
	Mapping / Documentation	laminationMappingDocumentation	0.7
	Test required	laminationTestRequired	0.6
	Length of deformity	laminationLengthOfDeformity	0.5
	Width of deformity	laminationWidthOfDeformity	0.5
Misaligned Member ***(MALM)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.7
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Contact spacing	surfaceContactSpacing	0.7
	Percent contact	surfacePercentContact	0.7
	Fill plate thickness	surfaceFillPlateThickness	0.5
	Fill plate specified?	surfaceFillPlate	0.7
	Full surface contact?	surfaceFullSurfaceContact	0.7
	Heat procedure approved?	surfaceHeatProcedure	0.7
	Member distance to correct location	mislocatedMemberDistanceCorrectLocation	0.5

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Misattached Member ***(MATM)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Stiffener type	stiffenerType	0.7
	Specified thickness	stiffenerSpecifiedThickness	0.2
	Specified width	stiffenerSpecifiedWidth	0.2
	Specified length	stiffenerSpecifiedLength	0.2
	Specified web thickness	stiffenerSpecifiedWebThickness	0.3
	Specified clip dimensions on web	stiffenerSpecifiedClipDimensionsOnWeb	0.3
	Specified clip dimensions on flange	stiffenerSpecifiedClipDimensionsOnFlange	0.3
	Specified spacing between stiffeners	stiffenerSpecifiedSpacingBetween	0.5
	Specified diaphragm or brace attachment?	stiffenerSpecifiedDiaphragmAttachment	0.5
	Specified flange attachment	stiffenerSpecifiedFlangeAttachment	0.7
	Specified tension flange attachment type	stiffenerSpecifiedTensionFlangeAttachmentType	0.7
	Specified compression flange attachment type	stiffenerSpecifiedCompFlangeAttachmentType	0.7
	Actual tension flange attachment type	stiffenerActualTensionFlangeAttachmentType	0.7
	Actual compression flange attachment type	stiffenerActualCompFlangeAttachmentType	0.7
	Actual category 'C' qualified?	stiffenerActualCategoryCFlange	0.5
	Actual tension flange clipped?	stiffenerActualTensionFlangeClipped	0.3
	Actual compression flange clipped?	stiffenerActualCompFlangeClipped	0.3
	Actual tension flange attached?	stiffenerActualTensionFlangeAttached	0.8
	Actual compression flange attached?	stiffenerActualCompFlangeAttached	0.8
Miscut Member ***(MCTM)***	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.8
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Error member specified length	errorMemberDesignLength	0.5
	Error member specified width	errorMemberDesignWidth	0.6
	Error member specified thickness	errorMemberDesignThickness	0.6
	Error member actual length	errorMemberActualLength	0.6
	Error member actual width	errorMemberActualWidth	0.6
	Error member actual thickness	errorMemberActualThickness	0.6
	Attached or Intersecting member specified length	attachMemberDesignLength	0.3
	Attached or Intersecting member specified width	attachMemberDesignWidth	0.3
	Attached or Intersecting member specified thickness	attachMemberDesignThickness	0.3
	Attached or Intersecting member actual length	attachMemberActualLength	0.3
	Attached or Intersecting member actual width	attachMemberActualWidth	0.3
	Attached or Intersecting member actual thickness	attachMemberActualThickness	0.3
	Error member stress level	stressErrorMemberLevel	0.9
	Attached or Intersecting member stress level	stressAttachMemberLevel	0.7
	Miscut occurs at	miscutMemberErrorOccursAt	0.7
	Member specified clipped?	miscutMemberSpecifiedClipped	0.6
	Member actually clipped?	miscutMemberActualClipped	0.6
	Clipped dimension correct?	miscutMemberClippedDimensionsCorrect	0.6
	Member actual sweep	miscutMemberActualSweep	0.5
	Member specified sweep	miscutMemberSpecifiedSweep	0.5

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Mislocated Hole ***(MLCH)***	*Bridge type*	bridgeType	0.2
	Error member type	errorMemberType	0.8
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Hole type	holeDetailsType	0.5
	Number of holes with errors	holeDetailsNumberWithErrors	0.5
	Number of holes in grouping	holeDetailsNumberInGrouping	0.5
	Actual bolt diameter	holeDetailsActualBoltDiameter	0.3
	Actual hole diameter	holeDetailsActualHoleDiameter	0.3
	Actual longitudinal hole spacing	holeDetailsActualLongHoleSpacing	0.5
	Actual transverse hole spacing	holeDetailsActualTransverseHoleSpacing	0.5
	Specified bolt diameter	holeDetailsSpecifiedBoltDiameter	0.3
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.3
	Specified longitudinal hole spacing	holeDetailsSpecifiedLongHoleSpacing	0.5
	Specified transverse hole spacing	holeDetailsSpecifiedTransverseHoleSpacing	0.5
	Partially drilled hole(s)?	holeDetailsPartDrilledHole	0.6
	Partially drilled hole diameter	holeDetailsPartDrilledHoleDiameter	0.3
	Partially drilled hole depth	holeDetailsPartDrilledHoleDepth	0.6
	Partially drilled hole coverage of specified hole (%)	holeDetailsPartDrilledHoleCoverage	0.7
	Hole boring Procedure	holeDetailsHoleBoringProcedure	0.2
	Hole distance from intersecting member	holeDistanceFromIntersectingMember	0.6
	Hole distance from error member	holeDistanceFromErrorMember	0.6
	Hole distance from member edge	holeDistanceFromEdge	0.7
	Hole distance from member end	holeDistanceFromEnd	0.7
	Hole distance to correct location	mislocatedHoleDistanceCorrectLocation	0.5
	Hole placed in wrong flange?	mislocatedHoleIncorrectFlange	0.8
	Reinforcing steel hole(s)?	mislocatedHoleReinforcingSteelHole	0.9
	Error due to additional row bored?	mislocatedHoleAdditionalRowHolesDrilled	0.7
	Holes meet edge & end distance specification?	mislocatedHoleEdgeEndDistanceSpecification	0.7
	Intersection at current location?	mislocatedHoleIntersectionCurrentPosition	0.8
	Specified hole pattern bored correctly?	mislocatedHoleSpecifiedHolePatternCorrect	0.7
	Hole pattern interferes with specified pattern?	mislocatedHoleInterfereWithSpecifiedPattern	0.8
	Intersection with additional bolt line?	mislocatedHoleIntersectionNewPosition	0.7

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Mislocated Member (MLCM)	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.8
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.8
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Intersection occurs?	mislocatedMemberIntersection	0.9
	Inverted placement?	mislocatedMemberInvertedPlacement	0.8
	Member distance to correct location	mislocatedMemberDistanceCorrectLocation	0.5
	Intersected item	mislocatedMemberIntersectedItem	0.5
	Stiffener type	stiffenerType	0.7
	Specified thickness	stiffenerSpecifiedThickness	0.2
	Specified width	stiffenerSpecifiedWidth	0.2
	Specified length	stiffenerSpecifiedLength	0.2
	Specified web thickness	stiffenerSpecifiedWebThickness	0.4
	Specified clip dimensions on web	stiffenerSpecifiedClipDimensionsOnWeb	0.2
	Specified clip dimensions on flange	stiffenerSpecifiedClipDimensionsOnFlange	0.2
	Specified spacing between stiffeners	stiffenerSpecifiedSpacingBetween	0.5
	Specified diaphragm or brace attachment?	stiffenerSpecifiedDiaphragmAttachment	0.7
	Specified flange attachment	stiffenerSpecifiedFlangeAttachment	0.2
	Specified tension flange attachment type	stiffenerSpecifiedTensionFlangeAttachmentType	0.2
	Specified compression flange attachment type	stiffenerSpecifiedCompFlangeAttachmentType	0.2
	Actual tension flange attachment type	stiffenerActualTensionFlangeAttachmentType	0.5
	Actual compression flange attachment type	stiffenerActualCompFlangeAttachmentType	0.5
	Actual category 'C' qualified?	stiffenerActualCategoryCFlange	0.7
	Actual tension flange clipped?	stiffenerActualTensionFlangeClipped	0.2
	Actual compression flange clipped?	stiffenerActualCompFlangeClipped	0.2
	Actual tension flange attached?	stiffenerActualTensionFlangeAttached	0.3
	Actual compression flange attached?	stiffenerActualCompFlangeAttached	0.3
	Actual out of plumbness (%)	stiffenerActualPlumbness	0.8
	Actual bottom within middle 50% of sole plate?	stiffenerActualMiddleOfSolePlate	0.8
Misshaped Hole (MSPH)	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.7
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Hole type	holeDetailsType	0.9
	Joint slip critical?	holeDetailsJointSlipCritical	0.8
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.5
	Actual hole elongation distance	holeDetailsActualDistanceElongated	0.7
	Slots at correct slope?	holeDetailsSlotsAtCorrectSlope	0.8
Missized Hole (MSZH)	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.5
	Attached or Intersecting member type	attachMemberType	0.4
	Error member location	errorMemberLocation	0.6
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Hole type	holeDetailsType	0.7
	Number of holes with errors	holeDetailsNumberWithErrors	0.4
	Number of holes in grouping	holeDetailsNumberInGrouping	0.4
	Actual bolt diameter	holeDetailsActualBoltDiameter	0.8
	Actual hole diameter	holeDetailsActualHoleDiameter	0.8
	Specified bolt diameter	holeDetailsSpecifiedBoltDiameter	0.8
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.8
	Holes meet edge & end distance specification?	holeDetailsEdgeEndDistanceSpecification	0.8

TYPE	ATTRIBUTE / FEATURE	INPUT PREDICATE	WEIGHT
Nicks & Gouges *(NAGS)*	*Bridge type*	bridgeType	0.5
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.6
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Nick or Gouge type	nickGougeType	1.0
	Nick or Gouge depth	nickGougeDepth	0.5
	Nick or Gouge length	nickGougeLength	0.5
	Error member actual thickness	errorMemberActualThickness	0.5
	Error member stress type	stressErrorMemberType	0.6
	Error member stress level	stressErrorMemberLevel	0.8
	Error member actual edge type	errorMemberActualEdgeType	0.4
	Nick or Gouge reduction of area	nickGougeReductionOfArea	0.8
	Number of nicks or gouges near location	nickGougeNumberNearLocation	0.5
	Nick or Gouge perpendicular to bolt hole?	nickGougePerpendicularToBoltHole	1.0
	Error member actual width	errorMemberActualWidth	0.4
	Error member specified width	errorMemberDesignWidth	0.4
	Error member actual length	errorMemberActualLength	0.4
	Error member specified length	errorMemberDesignLength	0.4
Partially Drilled Hole *(PDRH)*	*Bridge type*	bridgeType	0.4
	Error member type	errorMemberType	0.6
	Attached or Intersecting member type	attachMemberType	0.5
	Error member location	errorMemberLocation	0.5
	Error member classification	errorMemberClass	0.3
	Attached or Intersecting member classification	attachMemberClass	0.3
	Hole type	holeDetailsType	0.6
	Actual hole diameter	holeDetailsActualHoleDiameter	0.5
	Specified hole diameter	holeDetailsSpecifiedHoleDiameter	0.5
	Partially drilled hole depth	holeDetailsPartDrilledHoleDepth	0.8
	Error member actual thickness	errorMemberActualThickness	0.8
Stress Fracture *(SFRC)*	*Bridge type*	bridgeType	0.3
	Error member type	errorMemberType	0.7
	Attached or Intersecting member type	attachMemberType	0.7
	Error member location	errorMemberLocation	0.8
	Error member classification	errorMemberClass	0.5
	Attached or Intersecting member classification	attachMemberClass	0.5
	Error member stress level	stressErrorMemberLevel	0.8
	Attached or Intersecting member stress level	stressAttachMemberLevel	0.8
	Fatigue concerns	stressFatigueConcerns	0.8
	Stress fracture(s) ?	stressFractures	0.9
	Maximum gap between fracture(s)	stressMaxGap	0.6
	Number of fractures near location	stressNumberOfFracturesAtLocation	0.6
	Angle of bend at fracture(s)	stressAngleOfBend	0.5

APPENDIX C – EXAMPLE KNOWLEDGE CONVERSIONS

Example Rule Conversion

Original BFX Rules & Solution:

```
IF incorrect flange OF mislocated hole
AND error member location OF structure IS compression flange
AND number with errors OF hole details <= 6
AND NOT intersection current position OF mislocated hole
AND NOT intersection new position OF mislocated hole
THEN fix 06 OF repair


IF fix 06 OF repair
THEN text OF result := CONCAT( text OF result, conclusions and advice[3])


WITH conclusions and advice [3] := "Mislocated hole(s) has occurred.

REPAIR:

Intersection of existing member or holes does not occur at current
location or new placement location. Bolt mislocated holes with High
Strength bolts and double washers. Drill holes in flange at correct
location as specified."
```

Converted FIXS Rule & Solution:

```
if mislocatedHoleIncorrectFlange(true)
  and errorMemberLocation(compressionFlange)
  and holeDetailsNumberWithErrors(HoleDetailsNumberWithErrors)
  and HoleDetailsNumberWithErrors =< 6
  and mislocatedHoleIntersectionCurrentPosition(false)
  and mislocatedHoleIntersectionNewPosition(false)
  then ruleSolution(mislocatedHole_6).


% Rule Solution Definition:
% ruleSolution(Solution,Type,Id,Description,Details,Repair)

ruleSolution(mislocatedHole_6,mislocatedHole,`MLCH-R006`,`Repair
Mislocated Hole(s)`,[],
`Mislocated hole(s) has occurred.

REPAIR:

Intersection of existing member or holes does not occur at current
location or new placement location. Bolt mislocated holes with High
Strength bolts and double washers. Drill holes in flange at correct
location as specified.
`).
```

Example Case Conversion

Original CB-BFX Case with Solution:

```
(defcase
     (:name "sf2"
     :purpose "repair stress-fracture errors"
     :status :SUCC
     :environment
          (list     (make-fabrication-error
               :type-of-error 'stress-fracture)
               (make-stress-fracture
               :sf-bridge-type 'plate-girder
               :sf-member-type 'diaphragm-brace
               :sf-att-int-member-type 'intermediate-stiffener
               :sf-error-member-location 'web
               :sf-error-member-classification 'primary
               :sf-att-int-member-classification 'primary
               :sf-fractures 'yes
               :sf-number-of-fractures-at-location 2 )))
     '(REPAIR -
          Cracks occur in the vertical weld attaching the stiffeners to the
          web or else in the vertical weld connecting the floorbeam to the
          stiffener. Preheat. Remove the cracked weld using air-arc carbon
          gouging. Grind the gouged areas. Inspect the gouged areas using
          magnetic particle testing. Replace the removed weld metals by
          rewelding and then reinspect the crack area using magnetic
          particle testing not before 24 hours after welding is complete.
          )
     nil)
```

Converted FIXS Case with Solution:

```
% Case Solution Definition:
% caseSolution(Solution,Type,Id,Description,Details,Status,Features,Repair)

caseSolution(stressFracture_2,stressFracture,`SFRC-C002`,`Repair Stress
Fractures`,[],success,
  [
    bridgeType                          : plateGirder,
    errorMemberType                     : diaphragmBrace,
    attachMemberType                    : intermediateStiffener,
    errorMemberLocation                 : web,
    errorMemberClass                    : primary,
    attachMemberClass                   : primary,
    stressFractures                     : true,
    stressNumberOfFracturesAtLocation : 2
  ],
`Cracks occur in the vertical weld attaching the stiffeners to the web or
else in the vertical weld connecting the floorbeam to the stiffener.
Preheat. Remove the cracked weld using air-arc carbon gouging. Grind the
gouged areas. Inspect the gouged areas using magnetic particle testing.
Replace the removed weld metals by rewelding and then reinspect the crack
area using magnetic particle testing not before 24 hours after welding is
complete.`
).
```