New software under development

Reducing Fabrication Errors in Steel Bridges

By Kim Roddis and Zhong Liu

Fabrication errors in steel bridges need to be recognized and corrected properly and efficiently. To arrive at the best possible solutions, engineers need not only knowledge of material and fabrication specifications, but also experience and good understanding of practical limitations faced by fabricators.

At the University of Kansas, we are collecting cases and advice and making it available by computer. The software, *Fabrication error Indexed eXamples and Solutions* (FIXS), is a knowledge-based system to provide quick, possible solutions to fabrication errors suitable for use by multiple DOTs. The sharable database can lead to standardized solution procedures that would expedite bridge fabrication and would be expected to reduce fabrication costs.

The first attempt at a knowledge-based system for fabrication errors, called *Bridge Fabrication error solution eXpert system* (BFX), used a rule-approach. To overcome the rule-based expert system's restrictions, a case–based approach CB-BFX was investigated. The initial version of FIXS combined the rule and case approaches. The current version of FIXS has improved the knowledge level of the system, to provide solutions and examples to steel bridge fabrication errors with detailed graphical and instructive information as well as enhanced explanations using both rule-based and case-based reasoning.

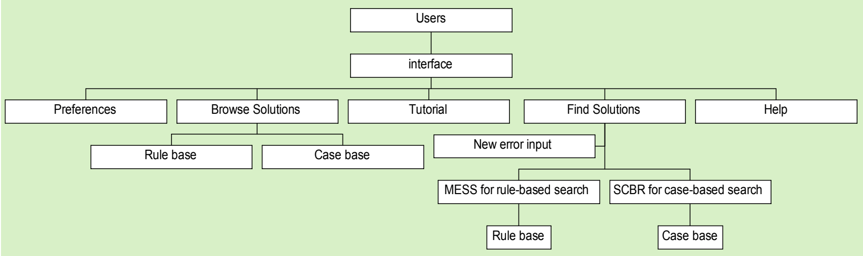

Figure 1: FIXS Program Structure

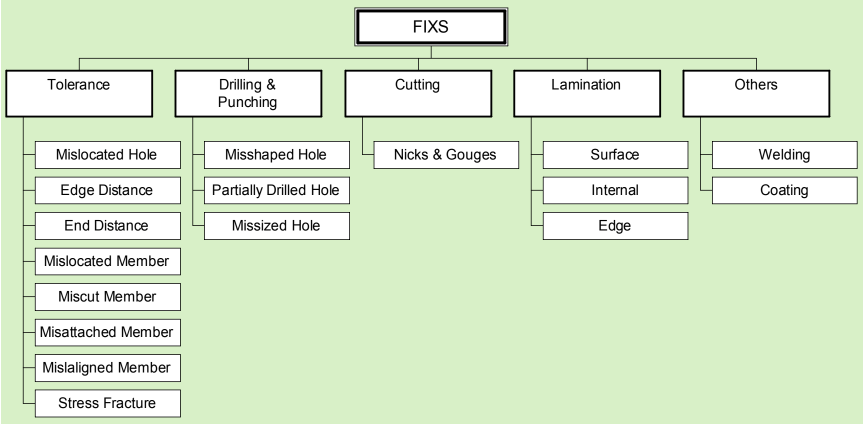

Figure 2: Structure of FIXS Knowledge Base

Description of FIXS

The current version of FIXS executes on Windows based operating systems. The user interface provides access to various tools as shown in *figure 1.*

The Preferences module allows the user to set such default values as maximum number of cases to return and lowest case similarity to return. The module Help gives access to the user manual containing directions on how to use the software. The Tutorial tool provides generic solutions and advice for detailing with the most common types of fabrication errors. Browse Solutions provides access to the complete rule and case bases grouped by the categories of errors. Find Solutions is the central tool that matches the user's description of a new error against the rule and case bases to find not only solutions recommended by the rules but also similar errors from the library of solved cases.

System Architecture

The development of FIXS required software tools that would allow construction of a collection of rules, a library of cases, mechanisms for searching through the rules and cases to recommend solutions, ways to explain how the solutions were found, and a user-friendly interface.

In FIXS, the rule–based approach and case-based approach are executed one after the other using the same input data. The rule and case answers are presented to the user together. The user interface provides use of an explanation facility, so the user may see a trace of the rule chain and the case similarities that lead to the answers provided.

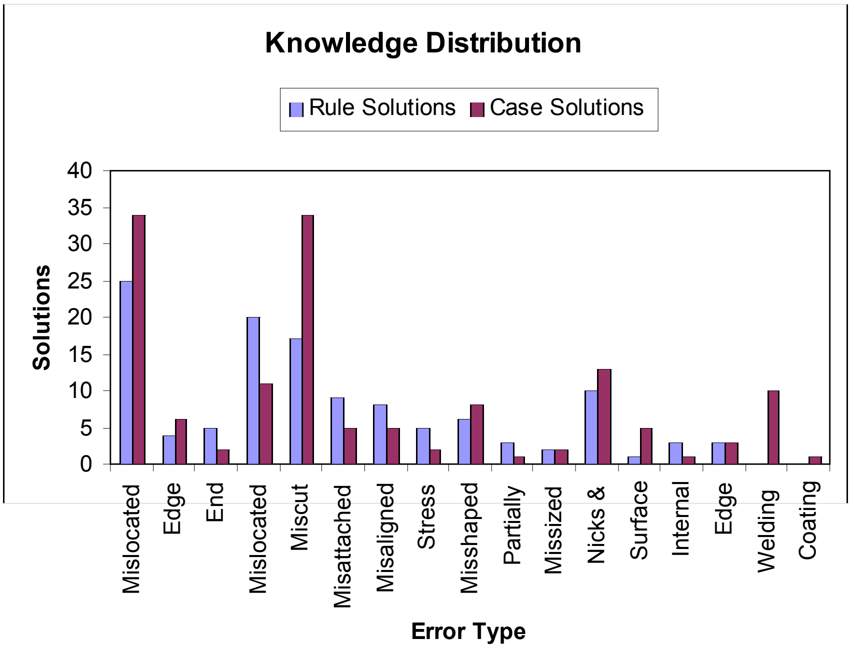

Figure 3: Distribution of FIXS Knowledge

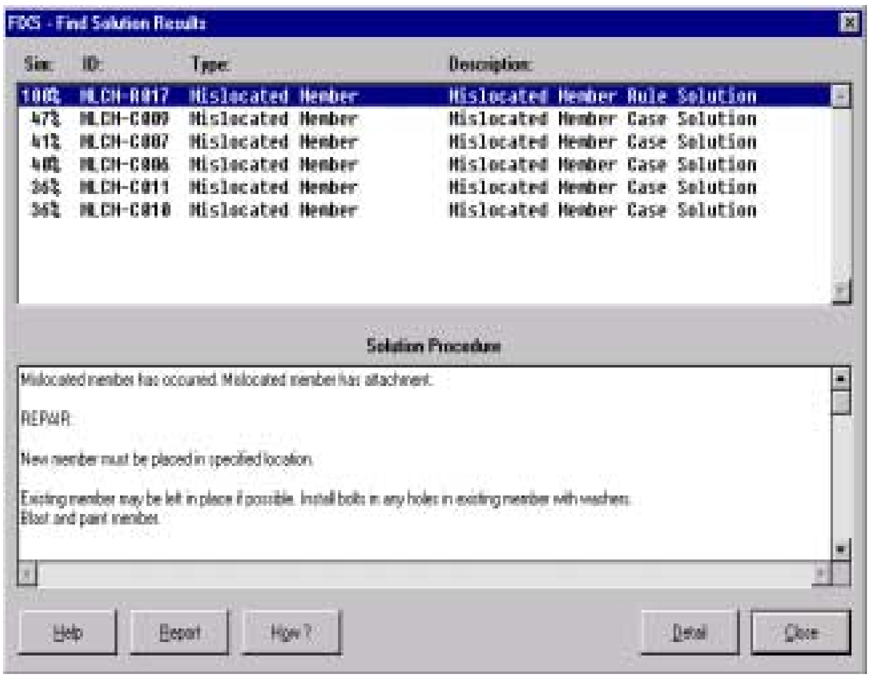

Figure 4: Solution Results Dialog

The knowledge about fabrication errors and solutions has been gathered from interviews with bridge engineers and fabricators, from fabrication shops, state inspectors' field notes, and bridge project documents. This information is then manually transferred to the knowledge base. Currently the knowledge base contains 121 rule solutions and 149 case solutions. These are divided into the five categories of Tolerance, Drilling & Punching, Cutting, Lamination, and Others. Each of the five categories is further divided into specific error types giving a taxonomy of common errors as shown in Figure 2. The number of solutions for each error type is given in the bargraph of Figure 3 to illustrate the distribution of the FIXS knowledge base.

Approximately 350 rules are used to search for rule solutions. FIXS uses a goal-driven search where the repair solutions are tested to see if the rule attributes/features associated with the repair have been satisfied so the repair solution can be triggered. This is basically a matching procedure where the applicable rules are selected from the rule base and used to construct a chain of reasoning that links the problem to the solution. The rule approach succeeds in finding a solution approximately two-thirds of the time.

Each case in the case library consists of header information, a feature list, and a solution procedure. Case matching in FIXS involves calculating and comparing the similarity of cases. Similarity values are calculated as the summation for similar features divided by the summation for possible features. For numerical features of each case, feature evaluations used in case matching are based on specified ranges of similarity.

"Why" and "How" functions are implemented to provide explanation during a search for a particular solution. "Why" explains why a particular piece of information is being requested by FIXS. "How" describes how a rule is being retrieved to build a reasoning chain. The Find Solutions dialog box can provide either a proof tree for finding a rule solution or a list of features required to locate a case solution of given error type. Rules and feature predicates are shown in a manner that is readable by users by converting predicate names and values to short descriptions.

In the FIXS main window, three main tools are available to locate error solutions: Find Solutions,

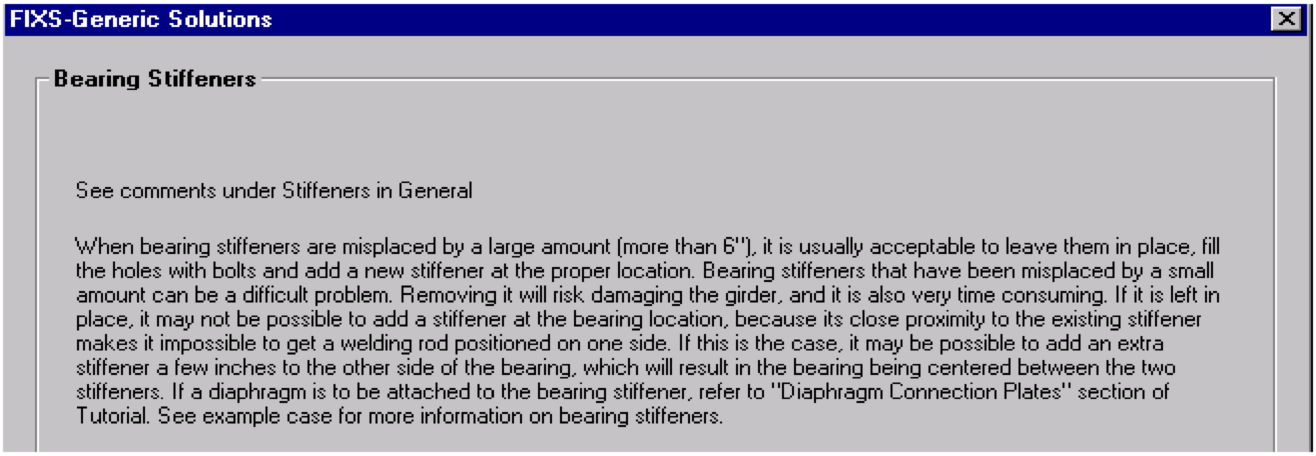

Figure 5: Tutorial Tool—Generic Solution

Case #NC501:
Description of Error: Bearing stiffeners welded in place out of plumb. Kick is 1 15/16" in lieu of 15/16".
Solution Recommended: Since bottom location of stiffener above the sole plate is correct and out of plumbness was less than 5%, stiffener was left in place and a shim used to bolt cross frame to stiffener.
Other possible solutions: Avoid removal unless absolutely needed so can avoid air arc gouging and grinding in the high stress bearing area. 1) If bottom location of stiffener is within middle 50% of sole plate, leave stiffener as is and check plumbness. If out of plumb more than 5%, weld additional stiffeners to create a shear panel (space new stiffeners between 6" and 12" on center. New stiffeners half the thickness of bearing stiffeners). Check cross-frame connection clearance. 2) If bottom location of stiffener is not within middle 50% of sole plate, add 2nd bearing stiffener.

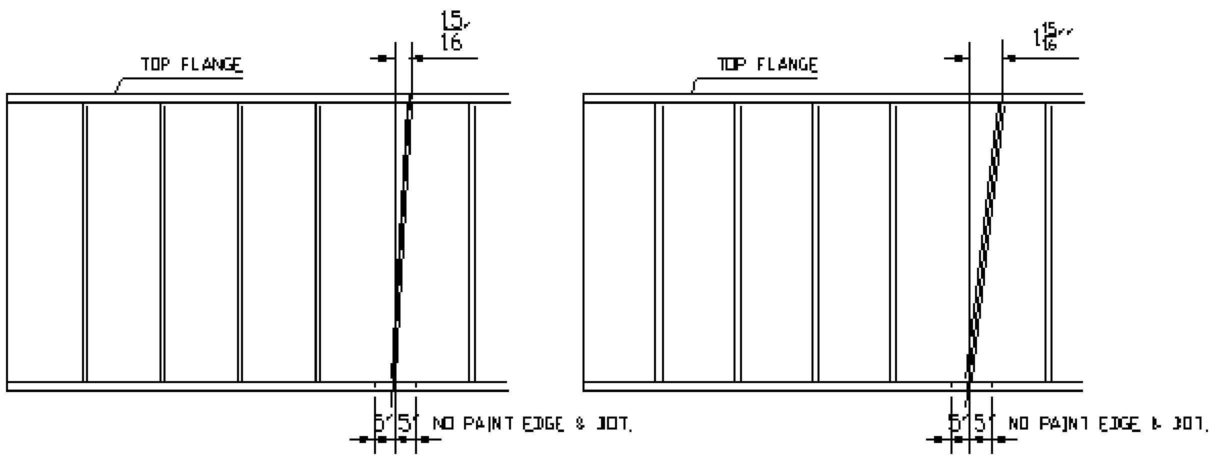

Figure 6: Case Description

Browse Solutions, and Tutorial. Find Solutions uses MESS to find a rule chain leading to a solution and SCBR to retrieve similar cases from the case library. Results of this search are ranked according to their similarity to the problem being solved. Figure 4 shows the Find Solutions Results screen for a misplaced bearing stiffener example. Find Solutions brings up a series of dialog boxes requesting multiple items to describe the fabrication error being solved. Browse Solution provides the user with a complete listing of all error solutions for a giving error type. The Tutorial tool provides the user with a set of categorized generic fabrication errors and solutions, collected from multiple DOTs and fabricators as well as generalized from actual cases. Because these errors are common, the tutorial information includes sketches and instructive comments to assist in categorizing situations and determining the best solution to offer the fabricator. Figure 5 shows the

Tutorial screen discussing mislocated bearing stiffeners.

An Example Use of FIXS

To illustrate the use of FIXS, let us take an example where an error has occurred involving the mislocation of a bearing stiffener. The user begins a session with FIXS and first chooses to look at the Tutorial. The "stiffener" portion of the Tutorial includes information on bearing stiffeners, as shown in Figure 5.

The user next selects Find Solutions and answers questions to give FIXS a description of the specific error. The rule-base and case-base are used in turn. Then the search results are summarized by FIXS as shown in Figure 4. In this example, one rule solution and five case solutions are found and listed in the upper portion of Figure 4. Since the rule solution has been selected in Figure 4, as can be seen by the black shading, the lower portion of Figure 4 shows the solution recommended from the rules. To see information on the case in FIXS library that most closely matches the example error, the user clicks on the second line of the upper portion of Figure 4. The case description shown in Figure 6 is then displayed.

Future of FIXS

FIXS has proven useful, but so far has had only limited distribution. Work is currently under way on a version to make the results of the previous FIXS project widely available and to enhance the repair database. This work is being sponsored by eleven states (IL, KS, MI, MN, MO, MT, NH, NV, PA, TX, WY). The funding is through a Federal Highway Administration pooled funds study with Kansas acting as the lead state. The objective is to develop a version of FIXS that is easily available to multiple state DOTs. The anticipated delivery mechanism is the World Wide Web. This includes selecting appropriate software tool, for web implementation, porting of the existing FIXS software to run in the web environment, and adding necessary features to support a web interface. Software enhancements need to be added to FIXS to readily address the needs of multiple DOTs. The repair database needs to accommodate information sharing while offering customization ability to suit individual DOTs.

To enhance the repair database, information will be gathered from DOTs and fabricators. This will include visits to fabrication plants, site trips, and consultation with bridge experts and targeted users. To ease information gathering, a web submittal mechanism will be developed.

In addition to the repair database itself, the project will produce a more thorough tutorial introducing bridge engineers to issues necessary for good resolution of fabrication error situations. This tutorial will provide not only recommendations of fixes to consider, but also examples of actions to avoid.

To ensure validity of information contained in FIXS, the knowledge base contents will be submitted to National Steel Bridge Collaboration membership for review and comment. FIXS currently only reacts to an error after it occurs. Fabricators and DOTs would mutually benefit from a more proactive approach to prevent errors from occurring in the first place. The results of the development and evaluation of the revised FIXS will be made available to encourage changes in practice to prevent the occurrence and ease the resolution of common fabrication errors.

Resolution of fabrication errors is just one example where similar problem situations are encountered on a semi-regular basis by a DOT organization but infrequently by an individual engineer. Feasibility of use of the developed technology for other applications in bridge engineering will be investigated and reported on.

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