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16. Abstract

Project 0-5574 "Curved Plate Girder Design for Safe and Economical Construction," resulted in the development of two design tools, UT Lift and UT Bridge. UT Lift is a spreadsheet-based program for analyzing steel girders during lifting while UT Bridge is a three-dimensional finite element program for analyzing partially or fully-erected steel girders during construction. The implementation project introduced these software tools to the Austin and Houston districts through hands-on training sessions. Through interviews, emails, and phone correspondence, TxDOT engineers provided the developers with feedback on modifications to the user interface necessary to improve the application of the software to TxDOT bridges. Based upon recommendations from TxDOT engineers, the software was modified. Training modules were also developed as a part of the training sessions. These training modules are distributed with the software so that new users can familiarize themselves with the software capabilities with well defined problems.

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Implementation Summary

1. Introduction

Project 0-5574 "Curved Plate Girder Design for Safe and Economical Construction," resulted in the development of two design tools, UT Lift and UT Bridge. UT Lift is a spreadsheet-based program for analyzing steel girders during lifting while UT Bridge is a three-dimensional finite element program for analyzing partially or fully-erected steel girders during construction. A major advantage of this software is the use of a graphical user interface (GUI) that allows users to create sophisticated computer models of the bridge during stages critical for stability, strength, and final position after deck casting. These models can be used to determine the necessity and placement of temporary construction supports as well as evaluating girder behavior during concrete deck placement.

The implementation project introduced these software tools to the Austin and Houston districts through a series of hands-on training sessions. Through interviews, emails, and phone correspondence, TxDOT engineers provided the developers with feedback on modifications to the user interface necessary to improve the application of the software to TxDOT bridges. Based upon recommendations from TxDOT engineers, the software was modified.

2. Training Modulus

To facilitate the implementation of UT Lift and UT Bridge, the research team developed a set of training modules to assist in the training of engineers utilizing the programs. The modules included an introductory PowerPoint presentation providing an overview of the two design tools and their capabilities. A problem focusing on girder lifting with the necessary information was developed for UT Lift with step-by-step instructions on how to solve the provided problem along with the solution for comparison. Three bridge problems were developed with a wide range of complexity to demonstrate the use of UT Bridge as well as the step-by-step instructions for program implementation. The result of going over the training modulus provided the participants a comprehensive overview of the software's features and capacity. Figure 1 shows the cover of one of the training modules. The modules were sufficiently complete so as to provide introductory guidance to new users. The documents that were developed for the training sessions are packaged with the software so that engineers obtain a copy directly when they download the software.

The first training session was provided on October 15, 2009, at the TxDOT Bridge Division in Austin, Texas. Several TxDOT engineers as well as outside consultants were present for the training. In addition to training the engineers present, constant feedback and dialog occurred providing the researchers with information to improve functionality and highlight areas where additional explanation within the program was necessary.

On November 3, 2009, the research team provided a day long training session for the Houston District in Houston, Texas. Several TxDOT engineers, as well as outside consultants, were present for the training. Additional feedback and dialog provided further information for the improvement of the programs.

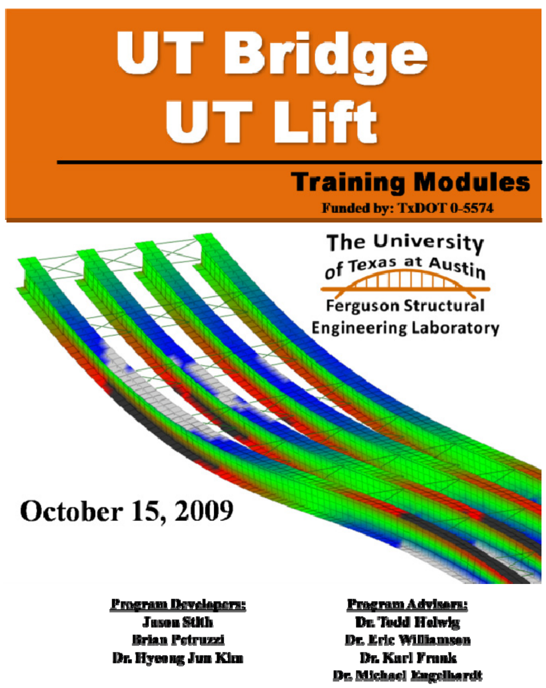

Figure 1: Training Modules for UT Bridge and UT Lift.

3. Debugging

Another important result of the implementation project was the ability to take feedback and errors that users found and fix programming errors. The debugging process was continuous throughout the implementation phase. Throughout the last year, the following errors were corrected:

UT Lift:

- Correction of the torsion diagram for girders lifted with cross-frames located only on one side of the girder

UT Bridge:

UT Bridge Pre-processor

- Corrected the span length calculation for negatively curved bridges with a skew

UT Bridge Processor

- Corrected the temporary support in-plane stiffness for curved bridges
- Corrected the node location algorithm for deck nodes placed between the girders
- Corrected the span length calculation for negatively curved bridges with a skew
- Corrected the support cross-frame member forces calculations
- Correct number of digits for 20+ analysis cases so that output files names are correctly named

UT Bridge Post-processor

- Correct display of information so that lines do not overlap rendering the information unreadable

4. Program Improvements

There have been a number of improvements in the software packages over the past year. One technical modification that was made was the incorporation of split-pipe stiffeners at supports. The pipe stiffeners are assumed to be constant thickness pipes split in half and welded to both flanges and the entire depth of the web. The integration of a warp restraining device into the girder-end frame connection can provide significant warping restraint and dramatically increase the girder's buckling capacity (Quadrato 2010). One analytical study found that the use of a pipe connecting the girder flanges can provide as much as a 70% increase in the buckling capacity (Ojalvo and Chambers 1977). The reason a pipe stiffener is effective in increasing the girder buckling capacity is shown in Figure 2. As the girder twists during buckling, the flanges undergo differential twist about the vertical axis through the web. The differential twist of the flanges is often referred to as warping deformation. The relative flange twist is represented in the figure by the flange ends rotating in opposite directions. For the flanges to twist relatively to one another, they must twist the pipe that connects them. Since the pipe is a closed shape it is torsionally stiff and provides a significant source of warping restraint that adds to the stability of the girder (Quadrato 2010).

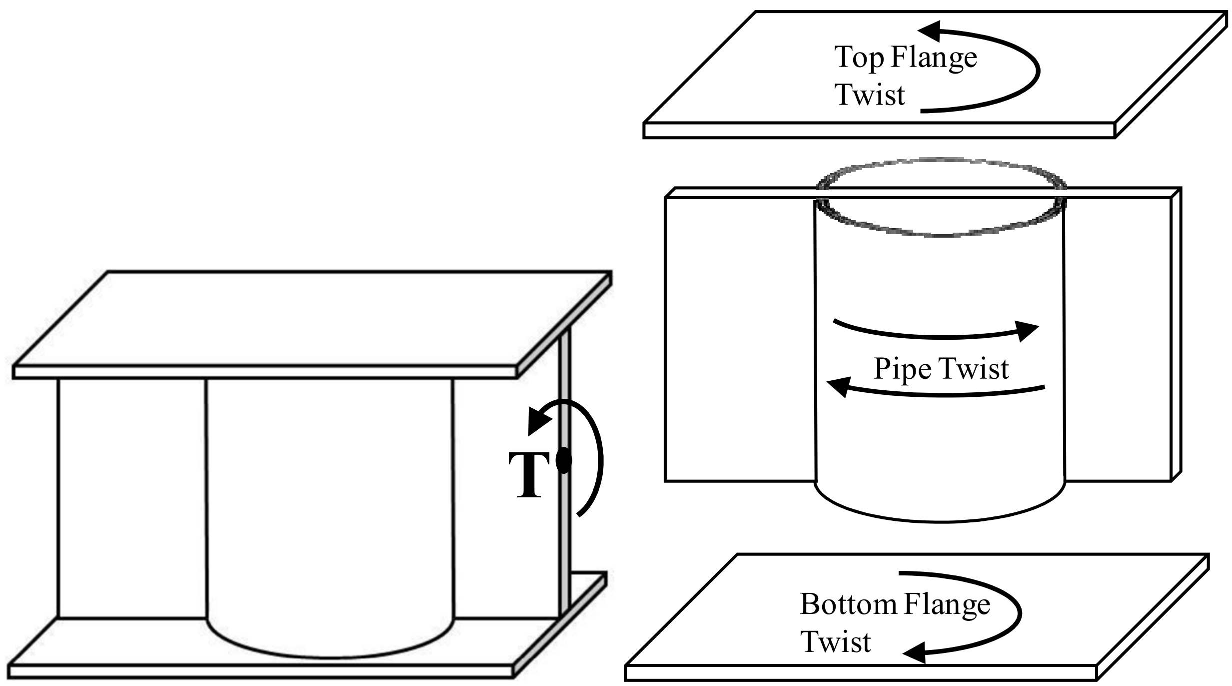

Figure 2: Pipe Stiffener Twist due to Flange Rotation Associated with Warping of the Girder's Ends (Quadrato 2010)

Within UT Bridge the pipe stiffener is modeled with a beam element similar to the plate stiffeners, but the appropriate bending and torsional properties are specified. Additionally, a stiff beam element is added to the top and bottom flange to couple the torsional degree of freedom from the pipe to the flange nodes. This must be done because the shell elements used in UT Bridge do not have a "drilling" degree of freedom.

The feedback from TxDOT and other users resulted in multiple improvements to the programs. The following section provides a summary of the improvements made during the implementation project over the past year.

UT Bridge:

UT Bridge Pre-processor

- Allow cut and paste within cells and tables of the forms
- Allow pipe-type bearing stiffeners to be specified
- Prompt user for the location of the folder path for saving output files
- Added save query prior to closing the program
- Updated output file to be compatible with changes
- Updated save file to be compatible with changes
- Made newest version backwards compatible with previous versions

UT Bridge Processor

- Added additional element type for pipe-type bearing stiffeners
- Calculated cross-frame location and girder information for post-processor
- Changed all stiffeners to full depth stiffeners
- Changed output file location to that specified by the user

UT Bridge Post-processor

- Provide cross-frame girder and location information
- Improved clarity of 3-D viewing field by moving display information
- Provide plan view button
- Provide list of reaction forces
- Provided different color (orange) for specified pipe stiffeners

5. Version Incremented

The original UT Bridge Beta 1.0 was completed on August 31, 2009. A webpage was set up at The University of Texas Ferguson Structural Engineering Laboratory website (http://fsel.engr.utexas.edu/software/) to provide the program to a wide audience. As corrections to known problems were made, the program was updated on the webpage with an incremented version. Updated versions of the software were made available on the following dates:

1. **UT Bridge Beta 1.1** – January 25, 2010
2. **UT Bridge Beta 1.2** – February 10, 2010
3. **UT Bridge Beta 1.3** – March 10, 2010
4. **UT Bridge 1.0** – August 24, 2010
5. **UT Bridge 1.4** – November 2, 2010

Shortly after the software version UT Bridge 1.0 was made available, problems were discovered with the programs ability to reference the input file. The problem has been corrected in the final version of the software that is currently available on the FSEL website. The current version works for MS Windows Vista and MS Windows XP operating systems. There are still problems with the MS Windows 7 operating systems; however the researchers are close to solving this problem and it will be made available for downloading as soon as the problem is fixed. Based upon a request from TxDOT, the final version of the software was changed from UT Bridge 1.0 to UT Bridge 1.4 to be consistent with the beta versions that are currently available.

6. Publication and Presentations

To increase the exposure of UT Lift and UT Bridge, the research team has presented on the capabilities of the programs at conferences. On November 19, 2009, the research team presented at the World Steel Bridge Symposium in San Antonio, Texas. On May 13, 2010, the research team presented at the Structural Stability Research Council (SSRC) annual meeting that was in conjuncture with the American Institute of Steel Construction (AISC) North American Steel Construction Conference and the American Society of Civil Engineers (ASCE) Structures Congress in Orlando, Florida. An additional presentation on UT Bridge's capabilities will occur on December 1, 2010, at the Transportation Research Board (TRB) Bridge Conference in San Antonio, Texas.

After the presentation at the World Steel Bridge Symposium, UT Bridge was chosen as the first ever AISC SteelTOOL of the month for March 2010. Additionally, a feature article was published in the June 2010 edition of AISC's Modern Steel Construction Magazine.

7. Conclusions

The implementation phase was successfully completed with the development of training modules, debugging the programs, updating features, and presenting the capabilities at conferences. Two-day long training sessions were performed that provided valuable feedback on usability. An updated version of UT Lift and three versions of UT Bridge Beta were created and made available through The University of Texas Ferguson Laboratory website. Presentations were made at several conferences to increase the exposure of the programs developed by The University of Texas and funded by TxDOT. More than 300 downloads of UT Bridge and approximately 200 downloads of UT Lift were recorded as of late October.

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Ojalvo, M., and R.S. Chambers (1977). "Effects of Warping Restraints on I-Beam Buckling." *ASCE Journal of the Structural Division* 103, no. ST12: 2351-2360.