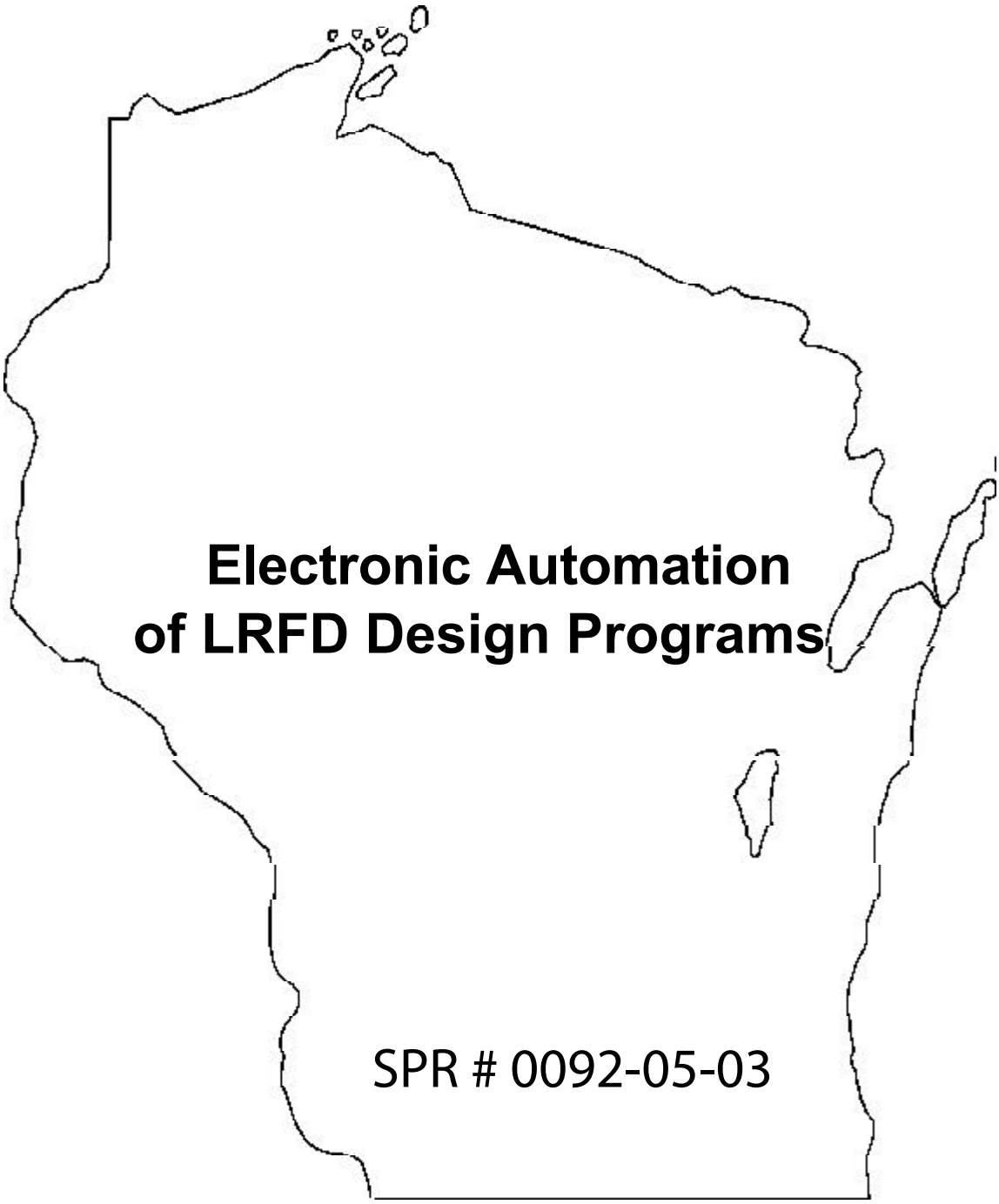
Wisconsin Highway Research Program



Electronic Automation of LRFD Design Programs

SPR # 0092-05-03

Sri Kanneganti and Tushar Desai

Bentley Systems Inc.

March 2010

WHRP 10-04

Disclaimer

This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration under Project # 0092-05-03. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Technical Report Documentation Page

1. Report No. WHRP 10-02	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Electronic Automation of LRFD Design		5. Report Date March 2010 6. Performing Organization Code
7. Authors Kanneganti, Sri; Desai, Tushar		8. Performing Organization Report No.
9. Performing Organization Name and Address Bentley Systems Inc. 510 Shotgun Rd. Suite 300 Sunrise, FL 33326		10. Work Unit No. (TRAIS) 11. Contract or Grant No. WisDOT SPR# 0092-05-03
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Division of Business Services Research Coordination Section 4802 Sheboygan Ave. Rm 801 Madison, WI 53707		13. Type of Report and Period Covered Final Report, 2004-2010 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The study provided electronic programs to WisDOT for designing pre-stressed girders and piers using the Load Resistance Factor Design (LRFD) methodology. The software provided is intended to ease the transition to LRFD for WisDOT design engineers. In addition to the software program, staff training was provided via Webinar and a User Manual was delivered.

17. Key Words	18. Distribution Statement
LRFD, Structures, Design	No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161

19. Security Classif.(of this report)	19. Security Classif. (of this page)	20. No. of Pages	21. Price
Unclassified	Unclassified		

Electronic Automation of LRFD Design Programs

For: Wisconsin Department of Transportation

By: Bentley Systems, Inc.

Project Number: 0092-05-03

Project Investigator (agency & contact): Bentley Systems, Inc. – Shri Bhide P.E., Ph.D.

Submittal Date: February 2010

Project Scope:

Provide for LRFD design of bridge superstructure and substructure (pier) elements using CONSPAN and RC-PIER software programs and develop code for their integration with existing Wisconsin DOT automated drafting software.

Project Status:

All phases of the technical and management aspects of the project including development of specifications, design, coding, testing and documentation have been completed by Bentley Systems and verified/accepted by Wisconsin DOT. A summary list of the deliverables is provided below:

- Control System: The control system is intended to allow the user to complete the design using minimum input information for the specific bridge design project, while using defaults based on Wisconsin DOT Bridge Design Manual. The design and analysis results will be available from the CONSPAN and RC-PIER engines (running in the background in a batch mode). The control system outputs the necessary information required for Wisconsin DOTs drafting system in an XML file.

- LEAP CONSPAN: Software for the design, analysis and load rating of pretensioned prestressed concrete bridge beams according to the AASHTO LRFD and Standard Specification codes.

- LEAP RC-PIER: Software for the integrated design and analysis of substructure elements according to the AASHTO LRFD and Standard Specification codes. LEAP RC-PIER allows users to design multi-column and hammerhead piers, straight, tapered or variable caps, and circular,

rectangular (tapered and non-tapered) or drilled-shaft columns. Footing types include isolated or combined, supported on either soil or piles

- Wisconsin DOT upgraded their standalone component licenses of CONSPAN and RC-PIER to LEAP Bridge as the project was nearing completion. Bentley Systems successfully updated the Control System to work with the CONSPAN and RC-PIER components within LEAP Bridge.

- The latest compiled versions of the LEAP Bridge application (and the design components CONSPAN and RC-PIER) have been delivered.

- The latest version of the source code for the Control System has also been submitted.

- A user manual developed as part of the documentation effort was completed and submitted.

- All user acceptance testing and verification have been completed and the project is considered closed.

Electronic Automation of LRFD Design

User Manual

v1.0.0

PROJECT NO: 0092-05-03 January 2010

TRADEMARK NOTICE

Bentley, the "B" Bentley logo, LEAP Bridge, LEAP CONSPAN, LEAP RC-PIER are registered or nonregistered trademarks of Bentley Systems, Inc. or Bentley Software, Inc. All other marks are the property of their respective owners.

RESTRICTED RIGHTS LEGENDS

If this software is acquired for or on behalf of the United States of America, its agencies and/or instrumentalities ("U.S. Government"), it is provided with restricted rights. This software and accompanying documentation are "commercial computer software" and "commercial computer software documentation," respectively, pursuant to 48 C.F.R. 12.212 and 227.7202, and "restricted computer software" pursuant to 48 C.F.R. 52.227-19(a), as applicable. Use, modification, reproduction, release, performance, display or disclosure of this software and accompanying documentation by the U.S. Government are subject to restrictions as set forth in this Agreement and pursuant to 48 C.F.R. 12.212, 52.227-19, 227.7202, and 1852.227-86, as applicable. Contractor/Manufacturer is Bentley Systems, Incorporated, 685 Stockton Drive,
Exton, PA 19341-0678. Unpublished - rights reserved under the Copyright Laws of the United States and International treaties.

COPYRIGHT NOTICE

© 2010, Bentley Systems, Incorporated. All Rights Reserved.
Including software, file formats, and audiovisual displays; may only be used pursuant to applicable software license agreement; contains confidential and proprietary information of Bentley Systems, Incorporated and/or third parties which is protected by copyright and trade secret law and may not be provided or otherwise made available without proper authorization.

DISCLAIMER

Although this program has been written and tested by Bentley Systems, Inc., no warranty, expressed or implied, is made as to the accuracy or functioning of the program and related program material. In no event will Bentley System, Inc. be liable for any damages, including, without limitation, incidental and consequential damages and damages for lost data or profits, arising out of the use of or inability to use the licensed program.

Table of Contents:

Chapter 1. Overview 3

Chapter 2. General Operation 4

2.1 Project Tab 4

2.2 Geometry Tab 4

2.3 Girder Tab 5

2.4 Pier Tab 9

2.5 Reactions Tab 13

2.6 Abutment Tab 14

2.7 Control Tab 15

2.8 File Menu 16

2.9 Help Menu 16

Chapter 3. Files 17

Chapter 1

Overview

The Control System (CS) software is a new component in the automated bridge design and drafting process at Wisconsin DOT. It augments the existing AASHTO Standard Specifications for Bridge (LFD) design module in use within the department by using LEAP CONSPAN and LEAP RC-PIER for LRFD design of both super and substructure components.

LEAP CONSPAN and LEAP RC-PIER are components of Bentley's LEAP Bridge suite of software in use at Wisconsin DOT.

- LEAP CONSPAN: Software for the design, analysis and load rating of pretensioned prestressed concrete bridge beams according to the AASHTO LRFD and Standard Specification (LFD) codes.

- LEAP RC-PIER: Software for the integrated design and analysis of substructure elements according to the AASHTO LRFD and Standard Specification (LFD) codes. LEAP RC-PIER allows users to design multi-column and hammerhead piers, straight, tapered or variable caps, and circular, rectangular (tapered and non-tapered) or drilled-shaft columns. Footing types include isolated or combined, supported on either soil or piles.

This user manual explains the general operations and file operations of the Control System only. The user should refer to the detailed user manuals for LEAP CONSPAN and LEAP RC-PIER for a complete understanding of the assumptions, engineering design and analysis concepts, general operation and output.

Basic Workflow:

The Control System can be run both in standalone mode or kicked off from the MicroStation environment. When run from MicroStation the input values in the Control System are automatically populated. Many of the design parameters (live load selection, concrete design parameters etc.) are already pre-defined in the Control System based on WisDOT standard practice. The user completes any other information required and completes the design of the component (either girders or substructure elements). After this the selected design results will be passed back to the drafting software for automated drafting. While the automated process runs the design software in a batch mode (with hidden user interface), users will be able to invoke and run CONSPAN or RC-PIER as standalone programs from within the Control System.

Chapter 2

General Operations

This chapter covers the concepts and operation procedures for the Control System, screen by screen. It also explains the program menu options available under File and Help.

2.1 Project Tab

The project tab is the first tab visible when the Control System is started. As can be seen in the figure below, general project information, including Project ID, Date, Engineer initials and general text description of the particular run or project are typically input in this tab. The design specification, either LFD or LRFD should also be set.

When the Control System is started from the MicroStation environment, the Project ID, the user initials (By) fields are automatically populated, and the fields are grayed out and cannot be edited.

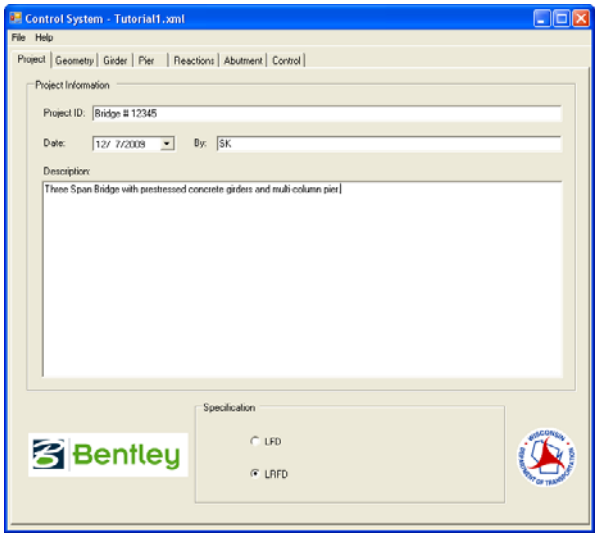


Figure 2.1.1 Project Tab

2.2 Geometry Tab

On the Geometry tab, users need to specify the bridge layout including number of spans, length of each span, skew angle at each support, deck width, curve-radius *(currently not used)*, and the left and right curb types from the pre-defined list.

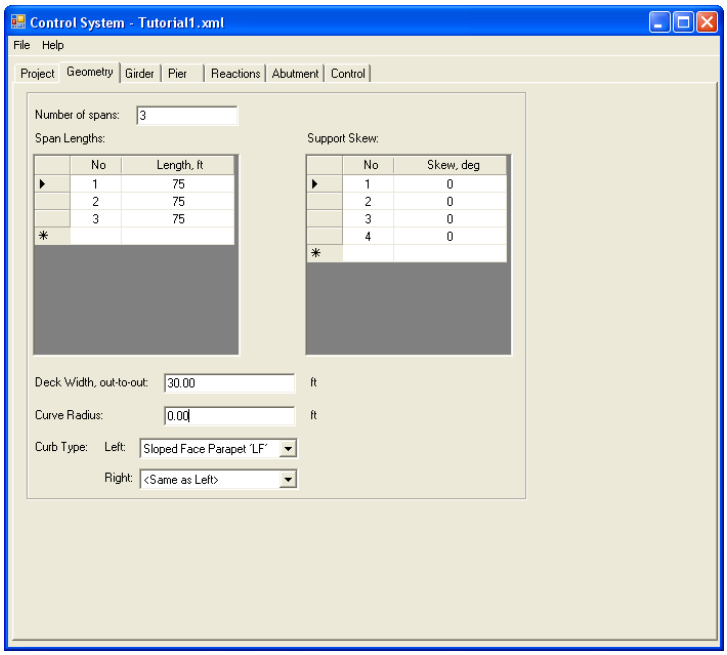


Figure 2.2.1 Geometry tab

The options for the curb are based on standard WisDOT curbs and include Sloped Face Parapet 'LF', Sloped Face Parapet 'HF', and Vertical Face Parapet 'TX'. These options come from settings in the Control tab as shown in Figure 2.2.2 below. The curb width is used by CONSPAN when placing the trucks in the transverse position for computing distribution factors by the Lever Rule method. The weight specified in the library for the selected curb is also used to populate the 'Curb (DC)' load in the Girder Tab.

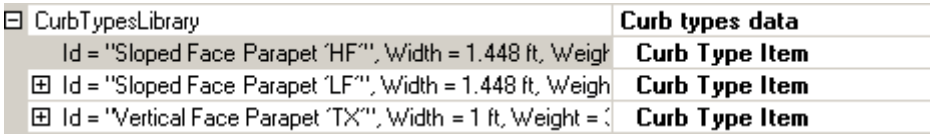


Figure 2.2.2 Curb Types in Control Tab.

2.3 Girder Tab

The girder tab is where additional bridge superstructure definitions are specified and the strand pattern design is completed. If the geometry data is complete, LEAP CONSPAN for girder design can also be run from this tab directly simply by clicking on the 'Exe & GUI' button, prompting the interface to be visible.

Prior to activating the user interface, the automated design process will be run for all beams in all spans. This allows for in-depth checking of the results, rather than simply a summary of number of strands for a strand design, or a 'NF' message when a pattern is not found. You cannot access the Control System without first closing CONSPAN.

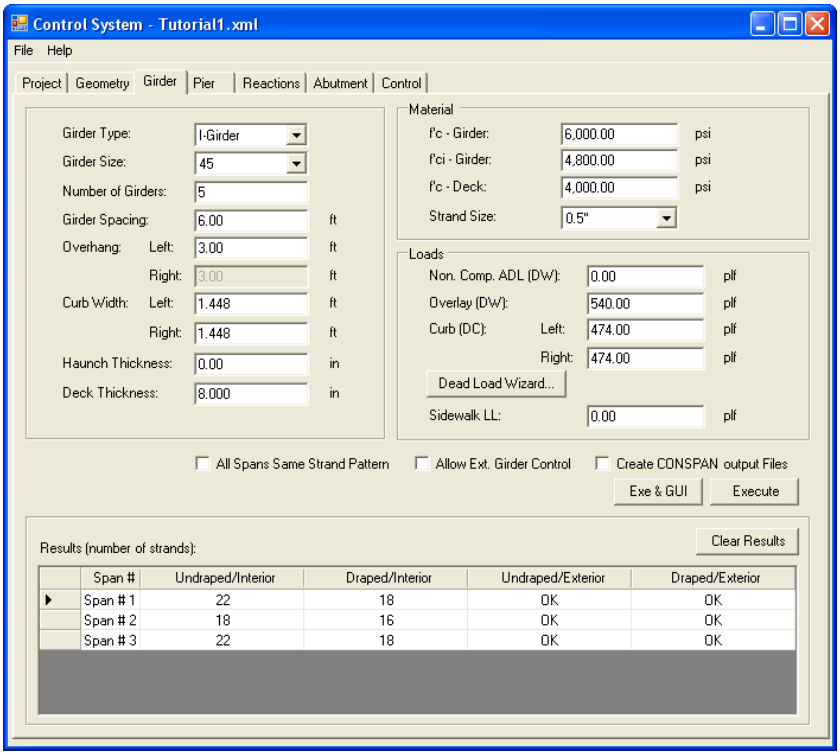


Figure 2.3.1 Girder Tab

The geometry of the bridge is specified by filling in the details of the Girder Type (either I-girders or Box Beams), the girder size, number of girders in the bridge cross-section, and their spacing. Once the left overhang distance (distance from edge of bridge to CL of exterior girder), the right overhang is automatically calculated. The spacing between the beams is assumed to be constant. The Curb Widths, left and right are auto populated by the selection on the Geometry tab. The material properties input include girder initial and final concrete strength, deck concrete strength and prestressing strand size. The prestressing strand sizes available are 0.5" and 0.6". These items are specified in the Control Tab under Strand Libraries as shown in Figure 2.3.2.

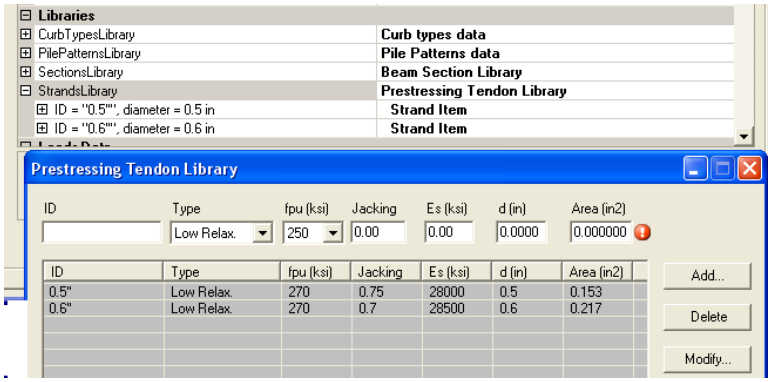


Figure 2.3.2 Prestressing strands library in the Control tab

Loads

Non composite (ADL) (DW): This is the load magnitude applied to each beam (precast load) as a DW (i.e. dead load of wearing surface) type of load. The sacrificial wearing surface (thickness) is grayed out in the Load Wizard, because it is expected that the user will specify the future wearing surface load per beam in the this field.

Overlay (DW): Model the weight of the Future Wearing Surface, if any.

Curb (DC): The curb weight is automatically filled in based on user selection for the curb type on the geometry tab. However it can edited in this field.

Clicking the Dead Load Wizard, will bring up the screen shown below in Figure 2.3.3, where the user can visually verify the input expected for the dead loads in the Control System. Data input here will not be stored in this screen, but is transferred to the dead load fields on the Girder tab.

Note: Right Barrier and Left Barrier Weight should be removed from the Permanent Load Wizard dialog, since user cannot enter any values for these. For now users should not input any values in these two fields.

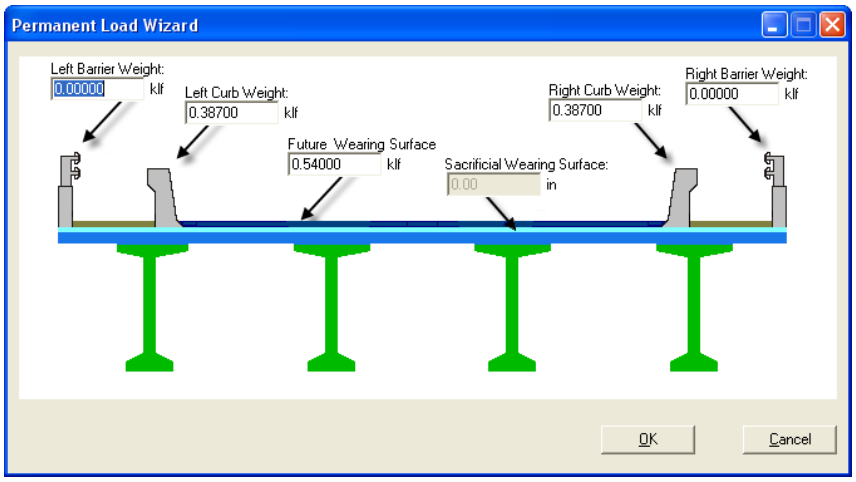


Figure 2.3.3 Dead Load Wizard

Please note that many of the common bridge parameters such as Live Loads on the bridge, or other design parameters/criteria is actually set in the Control tab. Since these parameters do not change for most routine bridge designs, they are hidden from view, and should not be changed other than by an administrator. Currently these fields are visible and editable, but in the future maybe locked down by a password.

Once all the input is complete, the user can simply check/set the appropriate design options and then click the Execute button (or alternatively the 'Exe&GUI' button). A brief explanation of the options is provided below:

a. All Spans Same Strand Pattern: When this option is not selected, the Control System will come up with a governing strand pattern for each span separately. If this option is checked however, it will come up with a strand pattern that works for all spans.

b. Allow Exterior Girder Control: WisDOT practice currently does not allow for exterior girder to control the design of the bridge girders. Rather than making all the interior beams have the same number of strands as the exterior, it is prudent to change girder spacing or overhang on exterior beam such that interior beam will control the girder design, in any particular span. However when using LRFD Specifications, there are many times, that exterior beam will control the design of the bridge. Selecting this option, will allow the program to check the interior beams against (/with) the exterior beam strand pattern automatically.

c. Create CONSPAN output files: Selecting this option will cause an output file for each beam in each span to be created in the working folder (as specified on the Control tab).

Execute : Once all data input is complete, clicking on this button causes CONSPAN to be run in the background (in batch mode) and automatically design strand all spans and all beams in the bridge, and summarize the results in the results table. The XML file for transferring information back to the drafting and detailing system is also generated in the working folder.

Exe & GUI: Similar to the Execute button functionality described above, but with the CONSPAN Graphical User Interface (GUI) visible. This enables more in-depth inspection of intermediate or final results.

Clear Results: Pushing this button will simply reset and clear the results in the Results table.

Results

Results (number of strands):

	Span #	Undraped/Interior	Draped/Interior	Undraped/Exterior	Draped/Exterior
▶	Span # 1	22	18	OK	OK
	Span # 2	18	16	OK	OK
	Span # 3	22	18	OK	OK

Figure 2.3.4 Results Grid

After the batch mode run in complete, the results grid is populated. Both a draped and an undraped strand pattern for both an interior and exterior beam in each span is evaluated, and the resulting number of strands are summarized.

NF: A strand pattern satisfying all ultimate moment and allowable stress criteria was not found.

NG: When the interior pattern was applied to the exterior beam, it did not pass the design criteria.

OK: When the interior pattern was applied to the exterior beam, it did pass the design criteria.

2.4 Pier Tab

The Pier tab features the following components:

1. Frame description
2. Cap, column and footing geometry definitions
3. Design reinforcement details for cap, column and footing.
4. Design summary.

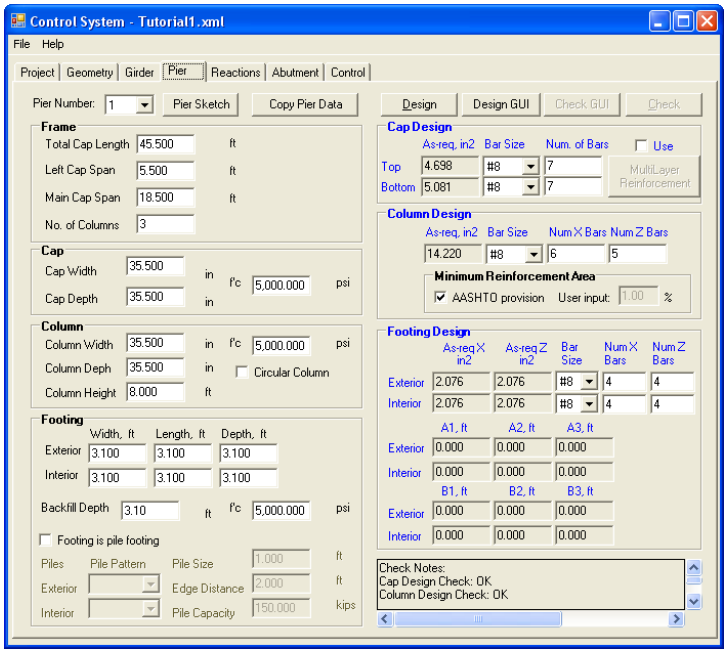


Figure 2.4.1 Pier Tab

Select the desired pier no, to design. Click on the Pier Sketch button to bring up a dialog which shows the definitions of the terms used for describing the geometry of the pier including cap, columns and footings.

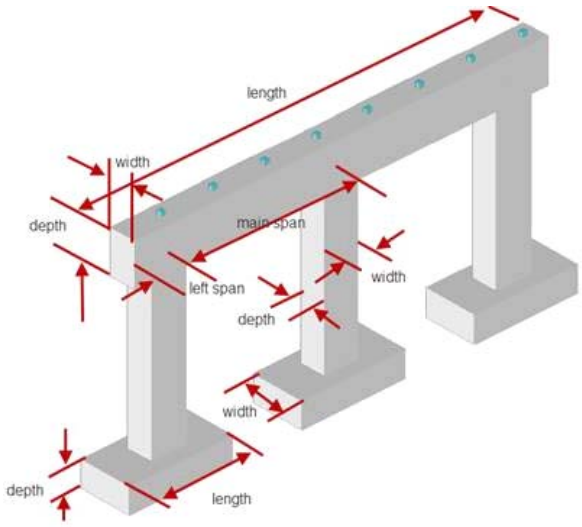


Figure 2.4.2 Pier Sketch

Pier Frame:

Define pier geometry details as shown below:

1. Total cap length: Overall length, (edge to edge distance) of the cap.
2. Left span defines the cap overhang as the distance from left edge of the cap to center line of column. Right span will be computed as
   Overall length – Main span * (no. of columns -1).
3. No. of Columns: Program will maintain the same spacing between columns as defined in main span.
4. Define cap and column dimensions. To define, circular column, select the option of circular and define column diameter. Note that, all the dimensions are in "inches."
5. Footing: User can define 2 types of footings:
   a. Spread
   b. Pile cap: To define, pile cap, select the check box for footing as pile footing. If this check box is not selected, program automatically designs footing as spread type.
6. Pile pattern: All the pile patterns are defined in the *.rp4, a library file pile pattern configuration. Please make sure, the library path is correctly setup in LEAP Bridge/ RC-PIER.

<u>Reactions from CONSPAN:</u>

If girders are already designed, then you can import CONSPAN live load reactions to RC-PIER. Please go to Reactions tab and select the box to use CONSPAN reactions in Live load generation.

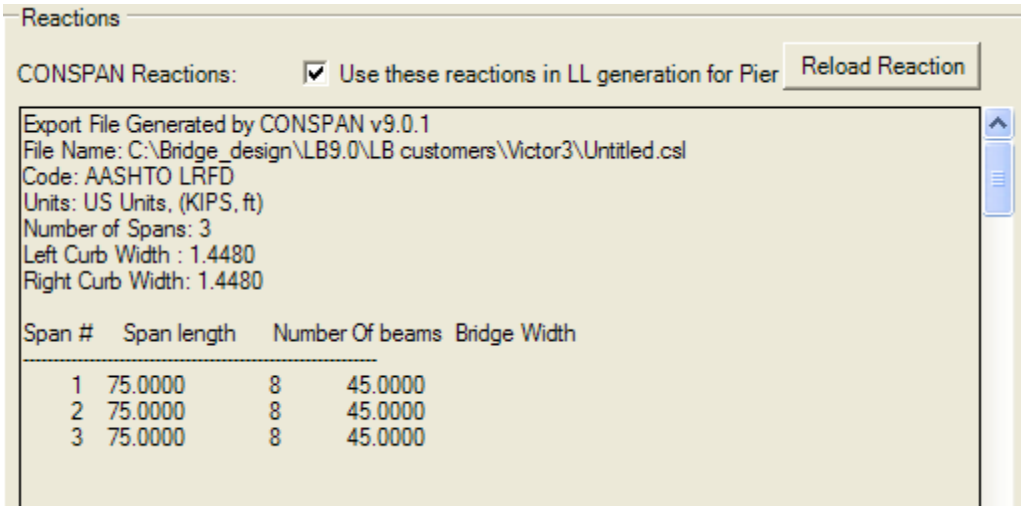


Figure 2.4.3 Reactions from superstructure analysis shown in reactions tab

Design:

By default, only Design and Design GUI will be enabled. Check & check GUI will be available only when user wants to overwrite the program generated design.

To design cap, click on Design. Control System runs RC-PIER in batch mode and returns the maximum number of rebars required to satisfy the design requirements.

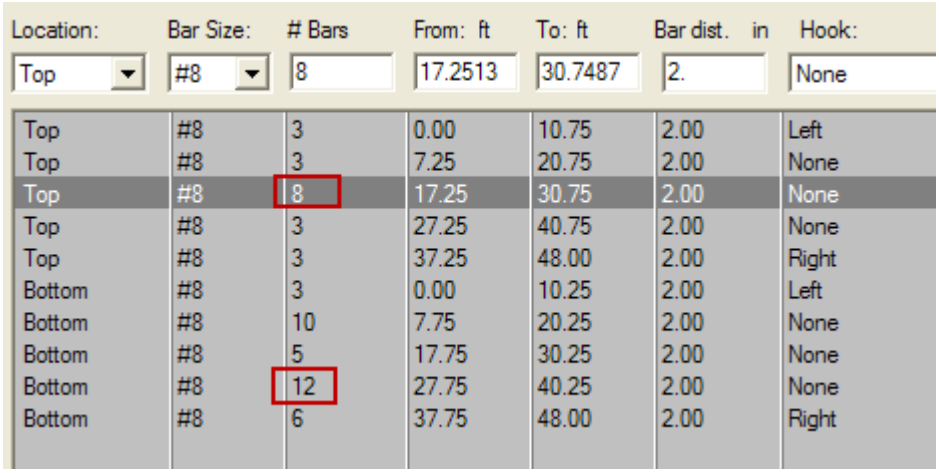


Figure 2.4.4 Reinforcement details in RC-PIER Cap Design

The Control System will show maximum top and bottom rebars from the above design results from RC-PIER.

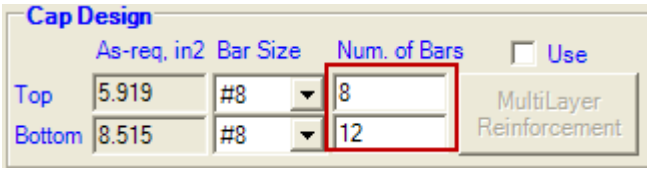


Figure 2.4.5 Cap Design in the Control Tab

If user wants to see more details, he can launch "Design GUI" option, which allows him/her to "review" the generated load cases and design details. Please use File| Print-> report to review any load generation and design details.

If user wants to overwrite the design, he can select bar size and number of bars and quickly check the design status. Also, to provide 2 layers of reinforcement, select "Use" check box and enter the rebar details in "Multilayer reinforcement" dialog as shown below. Note that, if you use multi layer reinforcement, program can only check the design. Auto design capabilities will be disabled.

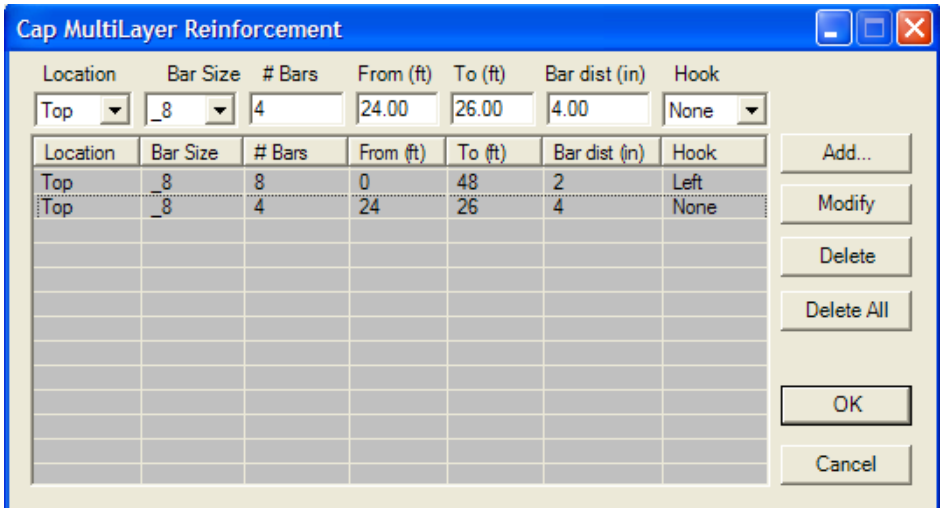


Figure 2.4.6 Cap Multi-layer reinforcement dialog

Column Design:

For column design, user must define the rebar size which needs to be considered for the design, in Control tab under "Other- Column rebar size".

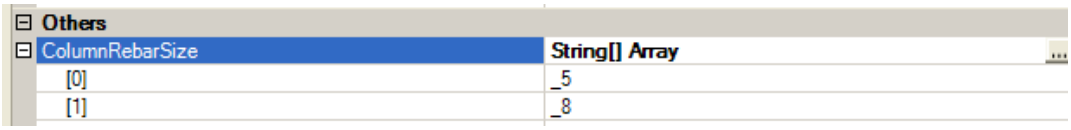


Figure 2.4.7 Setting the rebar sizes in the control tab

Similar to Cap design, design will run the program in batch mode and return the designed reinforcement. By default, program will use AASHTO provision for minimum reinforcement computation. User can overwrite this provision, by unchecking the AASHTO provision and define % value. Program will compute As_min reinforcement by multiplying this value with gross cross section area.

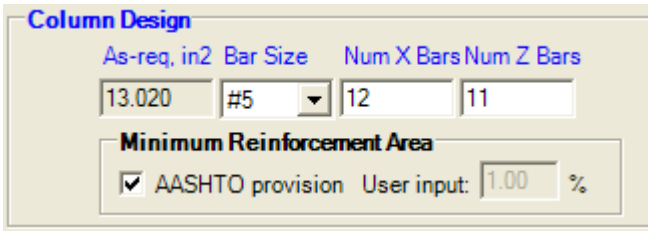


Figure 2.4.8 Column design options

Footing Design:

Similar to cap and column, footing design reinforcement will be shown for both internal and external footings. User can overwrite the reinforcement size and number of bars and check the design.

Design Summary:

Design Summary notes are shown at the bottom of the page. If all the AASHTO design requirements are satisfied, status will be “OK” for individual components; else it will be “Not OK” and program prints the special design notes for the engineer’s review.

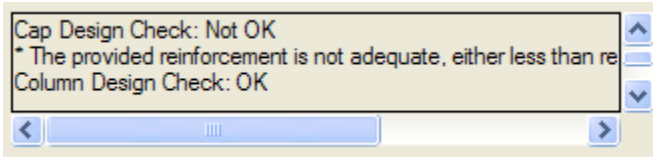


Figure 2.4.9 Design Summary notes

2.5 Reactions Tab

The reactions tab is available after the CONSPAN run, and shows the simple and continuous span results for all dead loads and live loads on superstructure. These reactions are used by RC-PIER when the check box for ‘Use these reactions in LL generation for Pier’ option is checked.

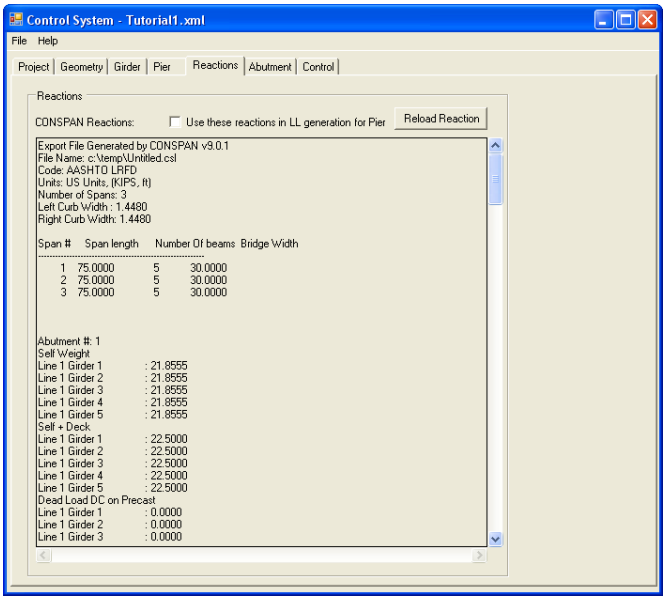


Figure 2.5.1 Reactions tab

The reactions from the superstructure analysis are written to a text file in the working folder with the file name ending with "-reactions.txt" and can be edited using note pad to overwrite any value. Clicking the 'Reload Reaction' button will load this file for use within the Control System.

2.6 Abutment Tab

Although you can use LEAP RC-PIER to design Pile Cap and Stem Wall type abutments, the integration with the Control System is not functional at this time. This tab is currently blank and simply acts as a place holder for future development.

2.7 Control Tab

The Control tab features settings for the superstructure and substructure engines as well as other design and analysis parameters that are not likely to change very frequently, or are standard values as per the WisDOT design manual. The values are set simply by editing the values in the Administration panel as shown in figure 2.7.1. These values are sent to the analysis/design engines automatically along with the other input data when the Execute buttons are clicked on the Girder tab and the Pier Tab.

The values in the Administration panel are saved to the ControlInfo.xml, and automatically reloaded every time the ControlSystem.exe is restarted.

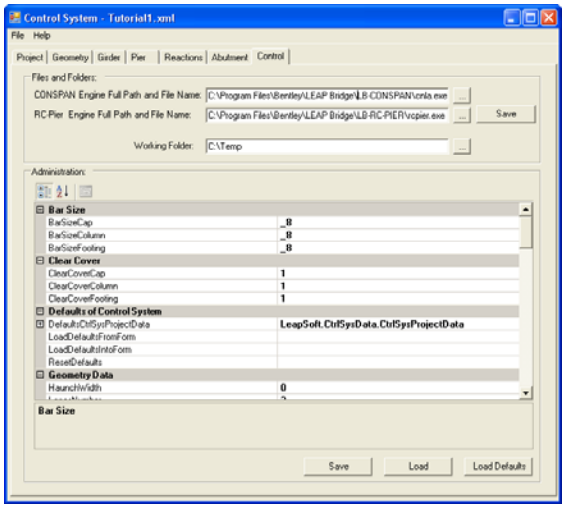


Figure 2.7.1 Control tab user interface

Engine Full Path and File Name: For each of the component programs, CONSPAN and RC-PIER, specify the path of the executable files. Hit the Save button near these fields to save it to the file UserSettings.xml file.

Working Folder: Specify folder where the CONSPAN or RC-PIER data files, and other xml file such as CnlaToCtrlSysData.xml and RcpToCtrlSysData.xml are output.

Save, Load: Allows the user to save changes made to the values in the Administration panel table, and load previously saved values from the ControlInfo.xml file back into the Administration panel table.

Administration panel: The user can edit the various values relevant to either superstructure or substructure design simply by clicking on the items in the grid. Users should hit the save button to save the values after editing. Some of the values such as SectionLibraries under the Libraries section have detailed dialogs that allow for detailed customized input as shown in the figure below.

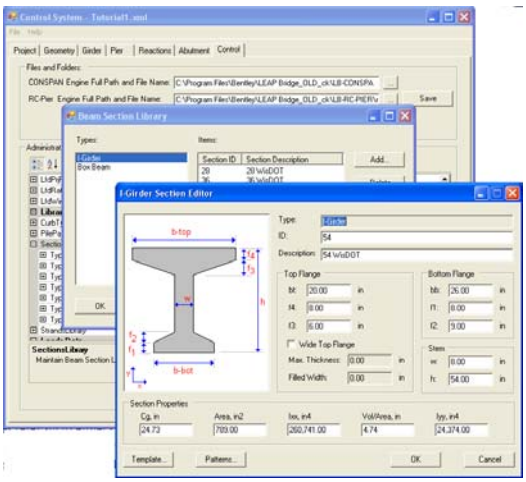


Figure 2.7.2 Sample dialogs for input of section properties of a BT beam.

Load Defaults: Predefined values (hard-coded in source code) are loaded into the table in the Administration panel.

2.7 File Menu

The functionality of the File menu options is explained below:

New: Closes currently open file, clears data and prepares Control System for new data.

Open: Brings up the File Open dialog and allows you to select a data file with the .xml extension.

Save: Saves the currently open file. Prompts you with the Save dialog if currently loaded file is untitled.

Save As: Allows you to save changes to the currently loaded data under a different file name.

Load RCP File: Allows you to specify and load an RC-Pier export file (xml data format) generated from the RC-PIER program.

Load Administrative Defaults: Not implemented yet. Currently resets all fields in the program.

Exit: Closes current data file, prompts for saving if data is changed and exits the Control System program.

2.7 Help Menu

The Help menu has two options:

User Manual: This brings up this user manual in PDF Format. Adobe acrobat reader (free) is required to be installed in order to read this manual.

About: Provides the version number of the Control System software.

Chapter 3

Files

The following is a list of all files used/generated during the operation of this software including input, output, settings and transfer files.

1. UserSettings.xml: This file is located in the same folder as the CtrlSys.exe file and contains info. about CN and RCP engine path and path of working folder.
2. ControlInfo.xml: This file is located in the same folder as the CtrlSys.exe file and contains info. about the Admin data as described in section 2.7 above.
3. CtrlSysToCnlaData.xml: This temporary file is created in the C:\ drive, and facilitates data transfer from the Control System to the CONSPAN program.
4. CtrlSysToRcpData.xml: This temporary file is created in the C:\ drive, and facilitates data transfer from the Control System to the RC-PIER program.
5. *FileName*.out: This output file is generated by RC-PIER and is created in the working folder set on the Control tab.
6. *FileName*_U_s1b1.txt: Optional CONSPAN output file generated for span # and beam #, with Undraped Strands in the working folder.
7. *FileName*_D_s1b1.txt: Optional CONSPAN output file generated for span # and beam #, with draped Strands in the working folder.
8. RcpToCtrlSysData.xml: RC-PIER output sent back to CtrlSys.exe through this xml file generated in the working folder.
9. CnlaToCtrlSysData.xml: CONSPAN output back sent back to CtrlSys.exe through this xml file generated in the working folder.

On the girder tab, if the option for 'Create CONSPAN output files' is checked, CONSPAN output files in text format with indepth design results are created for every beam in every span for both the draped (D) and undraped (U) strand patterns.

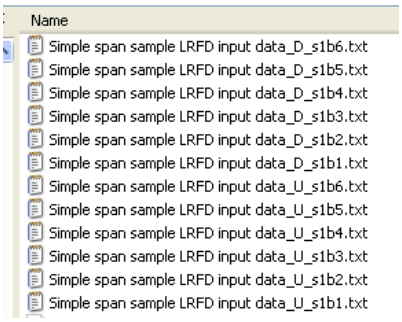


Figure 3.1 Sample listing of output files generated by CONSPAN

Wisconsin Highway Research Program
University of Wisconsin-Madison
1415 Engineering Drive
Madison, WI 53706
608/262-2013
www.whrp.org