



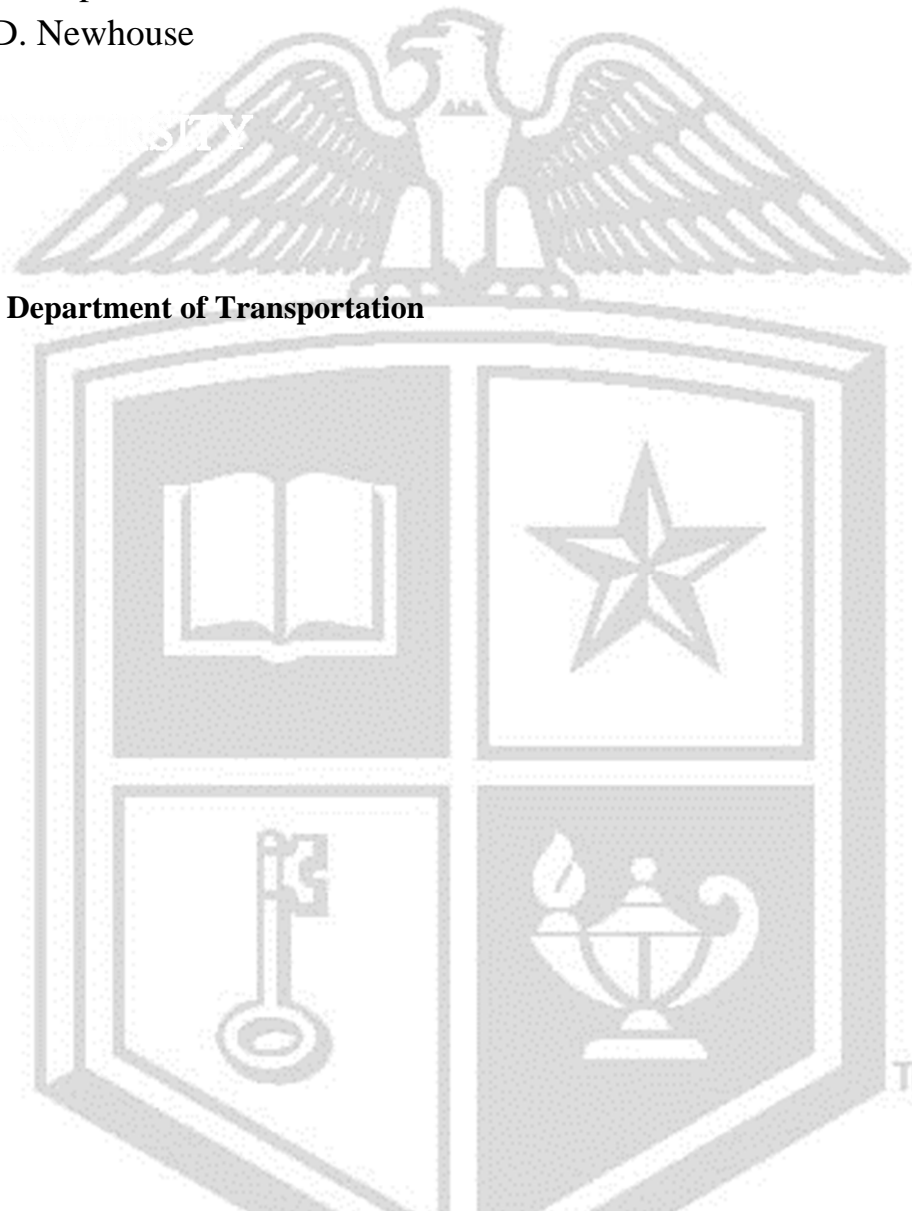
Texas Tech University
Multidisciplinary Research in Transportation

Software Development to Implement the TxDOT Culvert Rating Guide

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Priyantha W. Jayawickrama, Charles D. Newhouse

Performed in Cooperation with the Texas Department of Transportation
and the Federal Highway Administration

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| <p>Abstract:</p> <p>This implementation project created CULVLR: Culvert Load Rating, Version 1.0.0, a Windows®-based desktop application software package that automates the process by which Texas Department of Transportation (TxDOT) engineers and their consultants perform load rating calculations for reinforced concrete box culverts. Based on TxDOT's <i>Culvert Rating Guide</i>, the tasks associated with this project included programming the culvert rating process, software testing, creation of Help files, creation of the Install program, and beta testing. CULVLR is structured to accept reinforced box culvert input parameters in a manner typical of TxDOT design standards. The program uses these inputs to generate capacities for each critical section of the culvert structure. The load rater can select either Level 1 (CULV5) or Level 3 (RISA-3D) structural analysis software to generate demand loads, and CULVLR calculates load rating factors based on the calculated capacities and demands. Reporting functions allow the load rater to print summary, standard, or comprehensive reports.</p> | | | |
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by

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Products

This report contains no products.

ABSTRACT

This implementation project created CULVLR: Culvert Load Rating, Version 1.0.0, a Windows[®]-based desktop application software package that automates the process by which Texas Department of Transportation (TxDOT) engineers and their consultants perform load rating calculations for reinforced concrete box culverts. Based on TxDOT's *Culvert Rating Guide*, the tasks associated with this project included programming the culvert rating process, software testing, creation of Help files, creation of the Install program, and beta testing. CULVLR is structured to accept reinforced box culvert input parameters in a manner typical of TxDOT design standards. The program uses these inputs to generate capacities for each critical section of the culvert structure. The load rater can select either Level 1 (CULV5) or Level 3 (RISA-3D) structural analysis software to generate demand loads, and CULVLR calculates load rating factors based on the calculated capacities and demands. Reporting functions allow the load rater to print summary, standard, or comprehensive reports.

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INTRODUCTION

The Texas Department of Transportation (TxDOT) authorized implementation project 5-5849-01 for the purpose of creating a Windows®-based desktop application software package known as *CULVLR: Culvert Load Rating, Version 1.0.0* (Figure 1). CULVLR that automates the process by which TxDOT engineers and their consultants perform load rating calculations for reinforced concrete box culverts. Based on TxDOT's *Culvert Rating Guide* (TxDOT 2009), the tasks associated with this project included programming the culvert rating process, software testing, creation of Help files, creation of the Install program, and beta testing. This report summarizes the work performed in support of the software development process.

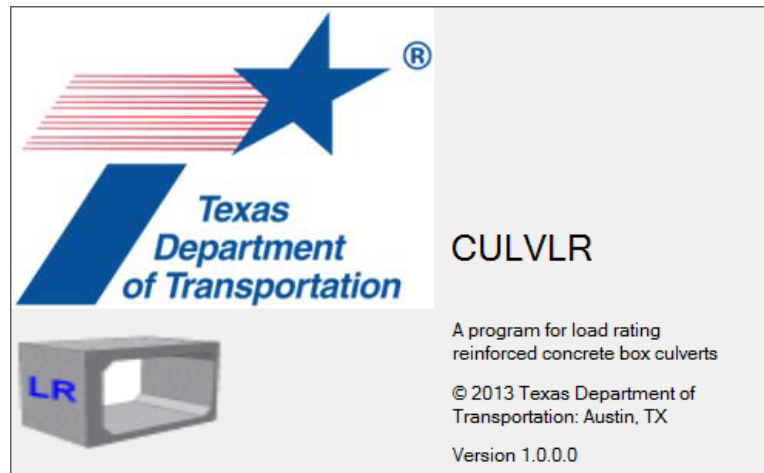


FIG. 1. Splash screen displaying CULVLR program identifiers

Automation of the culvert rating procedures presented in the *Culvert Rating Guide* was first suggested at completion of research project 0-5849. The recommendations section of the research report (Lawson, et al. 2010) envisioned a program that would "...automatically calculate culvert capacity and demands... and output the culvert load rating, critical section and failure mode." The CULVLR software developed through this implementation project achieves that objective.

Initiated through an administrative request from the TxDOT Bridge Division in January 2012, TxDOT formally authorized implementation project 5-5849-01 on May 30, 2012, with project oversight through RMC-5, Structures and Hydraulics. The project budget was \$74,288 and the overall project duration was twelve months.

THE CULVLR PROGRAM DEVELOPMENT PROCESS

Overview

The focus of this implementation project was to automate the culvert load-rating process articulated in TxDOT's *Culvert Rating Guide*. The software development process was designed to meet TxDOT architecture requirements at the time of delivery and involved the following steps:

- Create the Graphical User Interface (GUI) including user input and results display.

- Implement algorithms to determine demand loads as per the following levels of load rating, per the *Culvert Rating Guide*:
 - Level 1- based on a simplistic two dimensional frame model
 - Level 3 – based on a two dimensional finite element model that considers soil-structure interaction effects
- Implement algorithms to determine culvert capacity.
- Perform calculations to determine the culvert inventory rating and operating rating.
- Develop reporting functions.

The load demand calculations for culvert rating require application of published structural analysis software. As per the *Culvert Rating Guide*, we utilized the following published structural analysis software within the culvert load rating program:

CULV5: CULV5 is an MS-DOS program developed and distributed by the Texas Department of Transportation. The heart of the program is a two-dimensional frame analysis. Documentation supporting CULV5 includes the Version 2.2 Readme file (TxDOT 2012c), Input Guide (TxDOT 2012b), and CULV5 – Concrete Box Analysis Program (TxDOT 2012a).

RISA-3D (Release 10.0): RISA-3D is a commercially available three-dimensional frame analysis program (RISA Technologies 2012). Widely used throughout TxDOT, RISA-3D reasonably balances computational rigor against the unique requirements of the culvert rating problem.

CULVLR interfaces with these structural analysis programs by creating the input files needed for structural analysis to determine demand loads, and by receiving the output files upon completion of structural analysis. Concomitant analysis of the culvert structure as part of the culvert load rating process provides the load rater with the opportunity to review and evaluate load and deformation output from the structural analysis program prior to completing the load rating calculations.

Implementation Tasks

The specific tasks by which the research team developed the CULVLR software included:

Task 1. Develop Culvert Load Rating Program

Task 2. Testing of Culvert Load Rating Program

Task 3. Create Help Files

Task 4. Software Installation Program

Task 5. Beta Testing and Product Acceptance

Task 6. Project management

Tasks 1 and 2 were performed concurrently. Our approach was to create the software associated with the Level 1 load rating analysis (CULV5) and perform alpha testing for that part of the CULVLR program, and then to add the Level 3 load rating functionality (RISA) and perform alpha testing for that portion of the CULVLR program.

It should be noted that although CULVLR implements the load rating procedures presented in the *Culvert Rating Guide*, the programming process required that many aspects of the load rating process be adjusted, refined, and extended beyond the level of detail explained in the *Culvert Rating Guide*. Further, in some cases, CULVLR's features supersede the *Culvert Rating Guide*. For example, the *Culvert Rating Guide* only speaks of RISA-2D for Level 3 load ratings; whereas, TxDOT specifically required that CULVLR interface with RISA-3D even though Level 3 load rating is done based on a two-dimensional culvert model. Another example has to do with how CULVLR implements both AASHTO load rating policy (per the *Culvert Rating Guide*) and certain TxDOT-specific load rating practices. In cases where CULVLR goes beyond or supersedes the *Culvert Rating Guide*, program documentation explains the changes.

The user groups selected to test the culvert load rating software included the Texas Tech University program development team, TxDOT Bridge Division engineers, and TxDOT Technology Services Division programming personnel who served on the Project Monitoring Committee. The rationale for this approach was that all persons performing testing would be conversant with the culvert load rating process yet independent in the way they approached the culvert load rating problem. Further, TxDOT personnel represented the intended audience for the culvert load rating software package. All groups used the culvert load rating program to load-rate selected example culverts, and by so doing, perform error checks to verify the GUI properly handled inputs and produced valid output and reporting.

Task 3 through Task 6 focused on finalizing the overall functionality and usability of the software with a view to releasing the production version of CULVLR. The project development team performed these tasks concurrently and tested these features through the various alpha releases. Engineers and programmers from the TxDOT Bridge Division and Technology Services Division approved the final beta release of the complete CULVLR software package on January 31, 2013.

CULVLR PROGRAM FEATURES

CULVLR is structured to accept reinforced box culvert input parameters in a manner typical of TxDOT design standards. The program uses these inputs to generate capacities for each critical section of the culvert structure. The load rater can select either Level 1 (CULV5) or Level 3 (RISA-3D) structural analysis software to generate demand loads at these same critical section locations, and CULVLR calculates load rating factors based on the calculated capacities and demands. Reporting functions allow the load rater to print summary, standard, or comprehensive reports.

Program Input

Input tabs for CULVLR include culvert identification, geometry and material properties, reinforcing steel, section bar marks, and customizable section properties. These are designed to facilitate efficient entry of all parameters necessary for culvert load rating.

Figure 2 is a screen shot of the CULVLR graphical user interface showing the first input tab, 'Culvert Identification,' illustrating a three-barrel culvert.

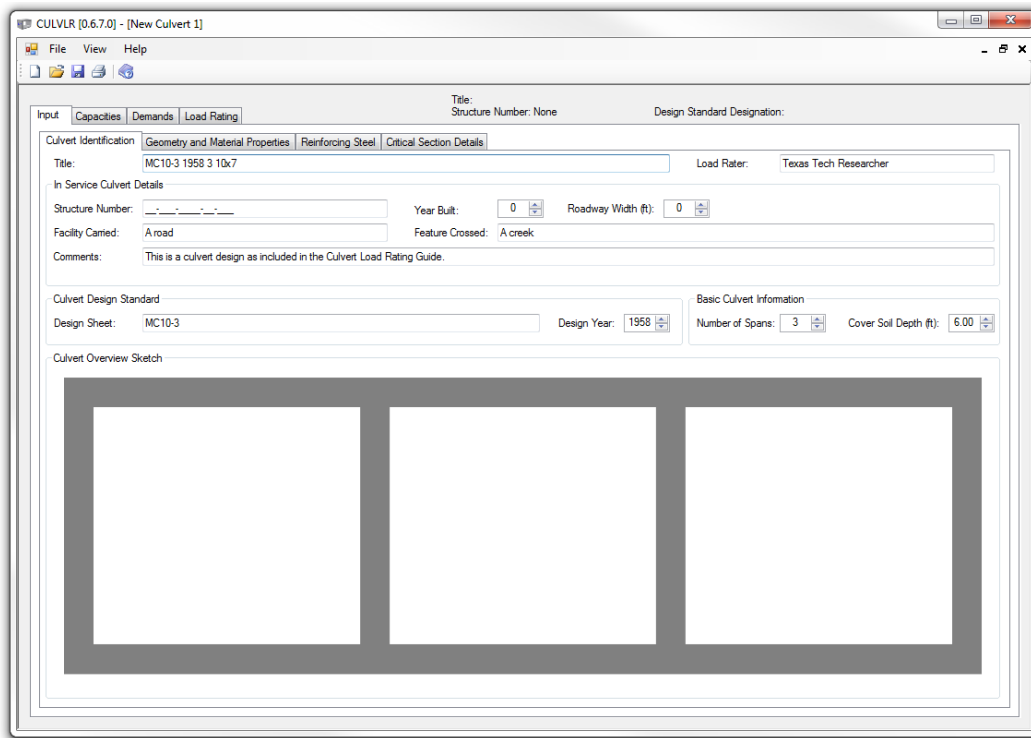


FIG. 2. Input tab for “Culvert Identification,” CULVLR

Once the basic culvert information is entered, the load rater clicks the second input tab, ‘Geometry and Material Properties,’ to continue. The ‘Geometry and Material Properties’ input tab facilitates identification of the culvert dimensions, typical slab and wall thicknesses, haunch dimensions (if present), reinforcing steel properties, and concrete properties. Entering these data yields a ‘Dimensional Sketch’ and an ‘Overview Sketch’ depicted in Figure 3.

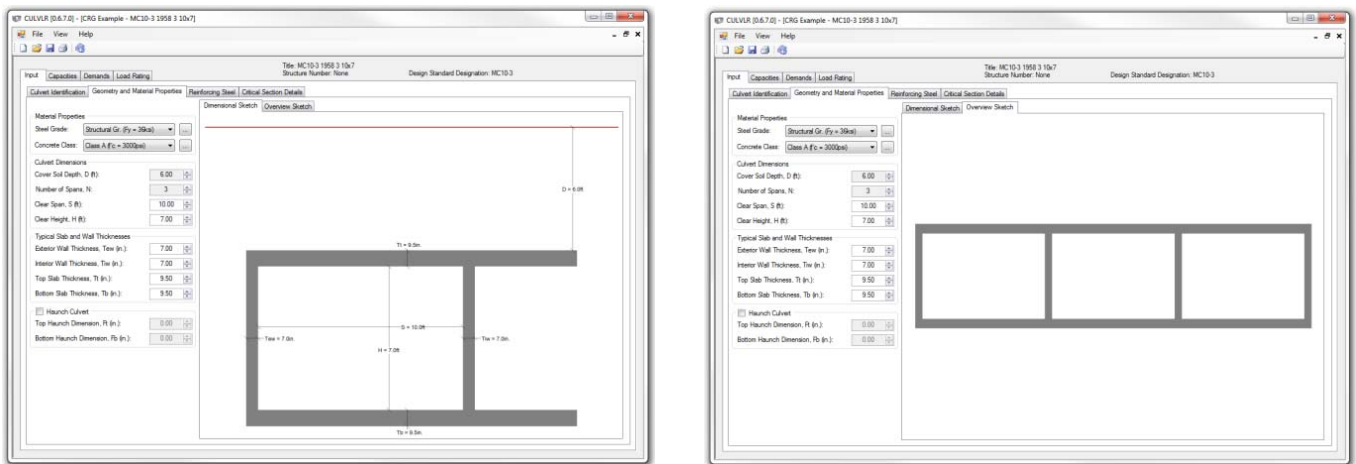


FIG. 3. Input tab for ‘Geometry and Material Properties’ showing the ‘Dimensional Sketch’ (left) and ‘Overview Sketch’ (right), CULVLR

‘Reinforcing Steel’ is the next input tab and contains five sub-tabs. The first sub-tab is used to input the steel schedule for the culvert, as shown in Figure 4. The four remaining sub-tabs are used to define the locations of the reinforcing steel by typical section; that is, ‘Typical Exterior Wall,’ ‘Typical Exterior Span,’ ‘Typical Interior Wall,’ and ‘Typical Interior Span.’ CULVLR uses these typical section definitions and the reinforcing steel schedule to extrapolate all the steel definitions in the whole culvert. Figure 5 shows a typical exterior span as an example. Each section on each sub-tab must be identified individually.

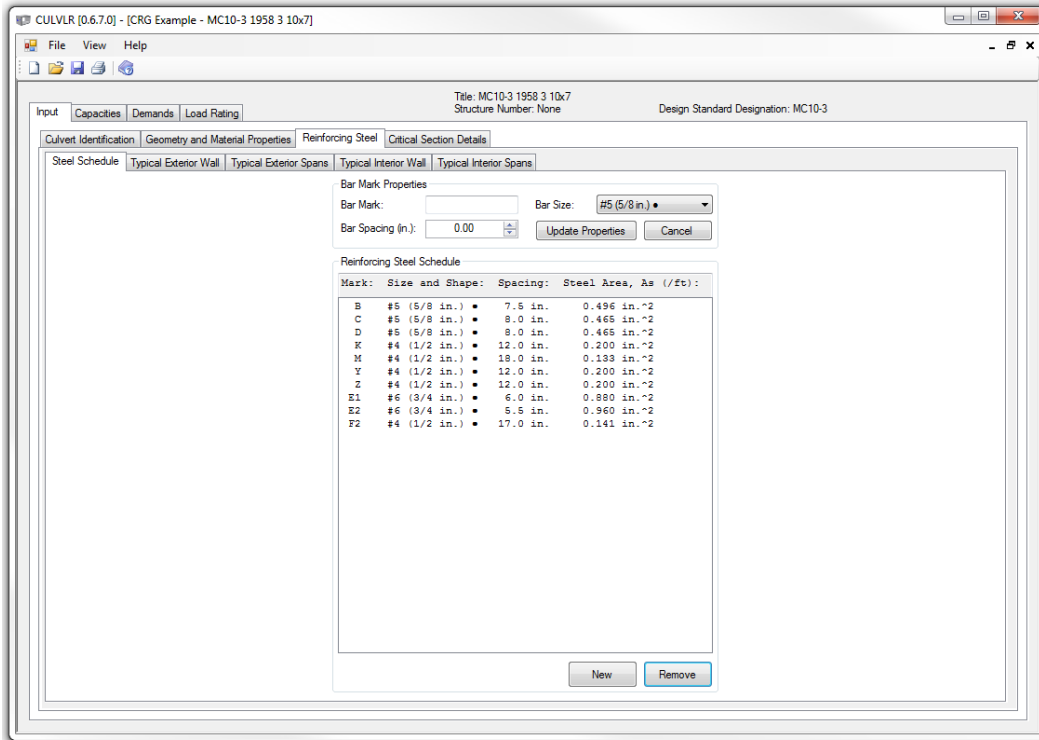


FIG. 4. ‘Steel Schedule’ sub-tab for ‘Reinforcing Steel’ input tab, CULVLR

Collectively, the first three input tabs facilitate entry of all parameters necessary to establish the structural design values for each critical section of the culvert. The ‘Critical Section Details’ input tab summarizes this information, by zone, as depicted in Figure 6. This figure reveals that our example three-barrel culvert has seven zones, one for each wall and one for each span. The critical section details in Figure 6 apply to an outside wall, as indicated by the culvert overview sketch located above the detailed section data. Alternatively, a four-barrel culvert would have nine zones, and so on, with CULVLR automatically formatting this input tab based on the number of culvert spans. In this way, the ‘Critical Section Details’ input tab presents all critical section data for the culvert structure.

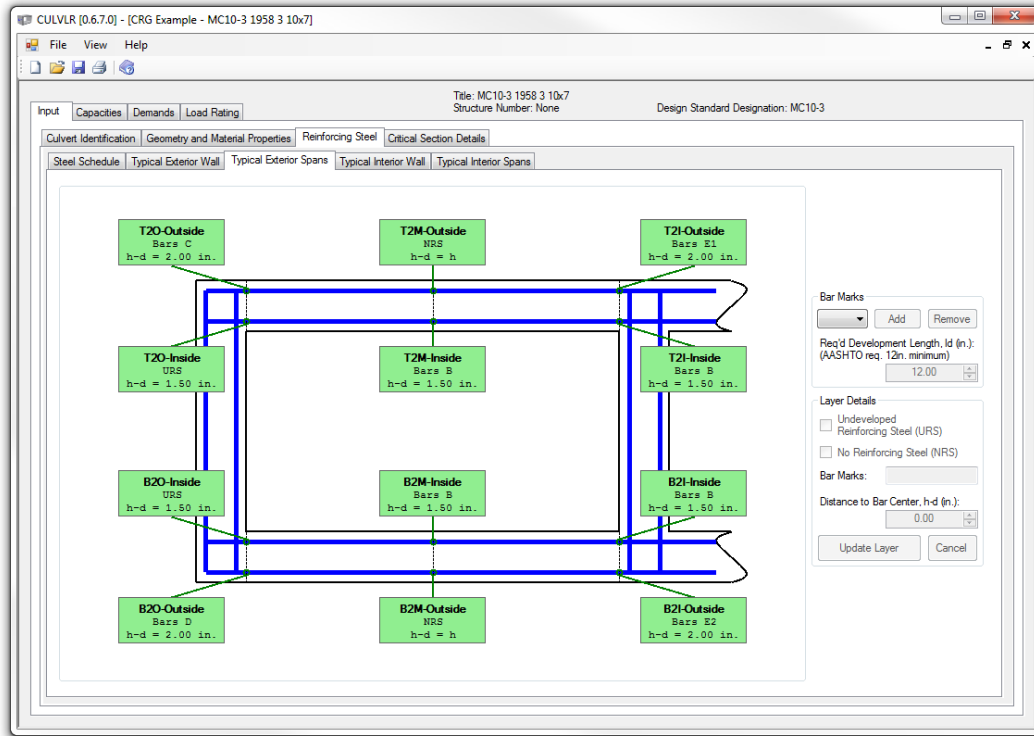


FIG. 5. 'Typical Exterior Span' sub-tab for 'Reinforcing Steel' input tab, CULVLR

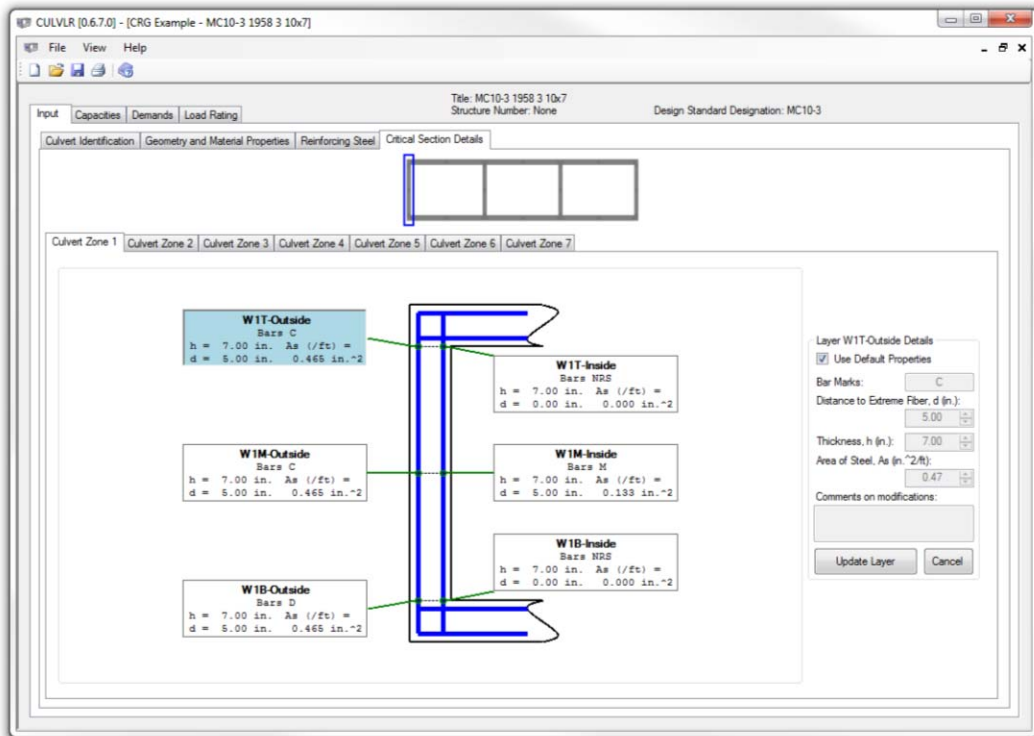


FIG. 6. 'Critical Section Details' input tab, CULVLR

Capacity Calculations

Completion of the data entry process facilitates automatic calculation of all structural capacity values for each critical section for each type of load. This includes positive and negative bending moment, positive and negative shear, and axial thrust. Figure 7 is a screen shot of the CULVLR graphical user interface showing the ‘Capacities’ tab associated with the example three-barrel culvert.

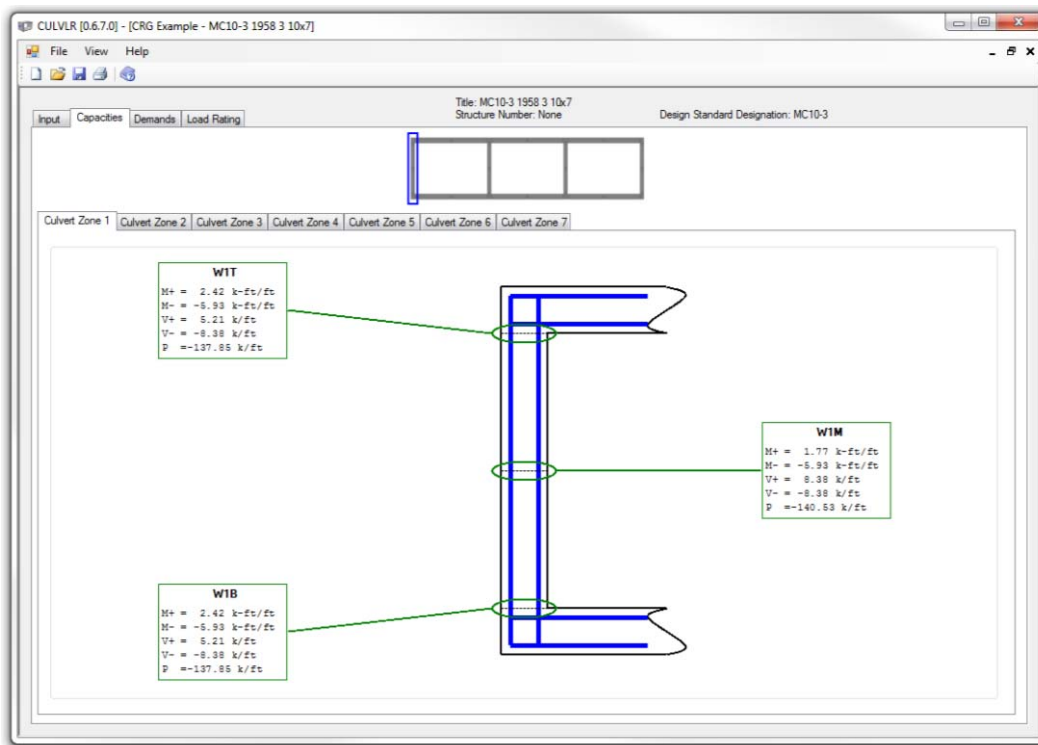


FIG. 7. ‘Capacities’ tab, CULVLR

Similar to the ‘Critical Section Details’ input tab, the ‘Capacities’ tab summarizes capacity information for all critical sections, by zone. This figure includes the culvert overview sketch above the detailed capacity sketch to facilitate keeping track of the critical section under consideration.

Demand Modeling

In practical terms, culvert load rating is accomplished by comparing structural capacity to demand load at each critical section of the culvert. Whereas capacities are established from the culvert geometry and material properties, demand loads must be obtained through analytical modeling. The ‘Demands’ tab, depicted in Figure 8, accomplishes this for CULVLR.

As noted earlier, CULVLR provides the load rater with several demand modeling options. The most fundamental issue is whether the load rater wants to use CULV5 – a structural frame model – to calculate demands, or use RISA-3D – which uses a soil-structure finite element model. The pop-up window in Figure 8 assumes the load rater has selected CULV5 as the analysis level in this particular example. A second issue has to do with the soil properties the load rater wishes to use. CULVLR provides two preset soil options for CULV5 and three preset soil options for RISA-3D. Project-specific values are also possible.

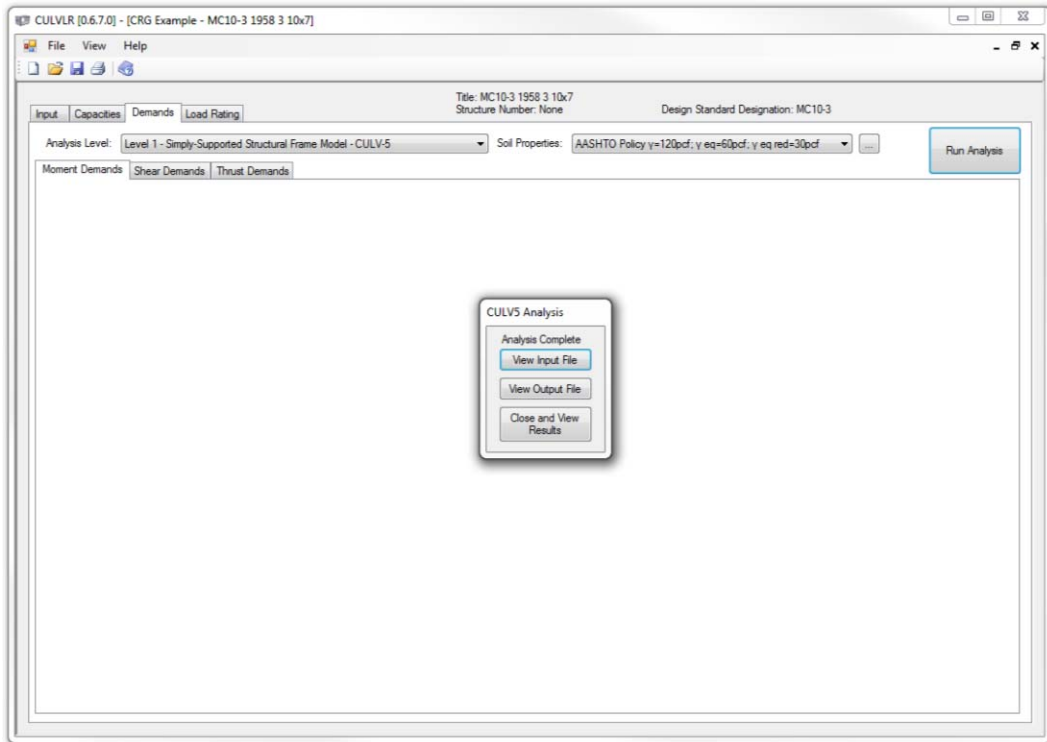


FIG. 8. 'Demands' tab, CULVLR

Although details of how to perform the two different structural modeling approaches are outside the scope of this report, suffice to say that the 'Demand' tab accomplishes demand modeling and this yields the demand loads for each critical section, as shown in Figure 9.

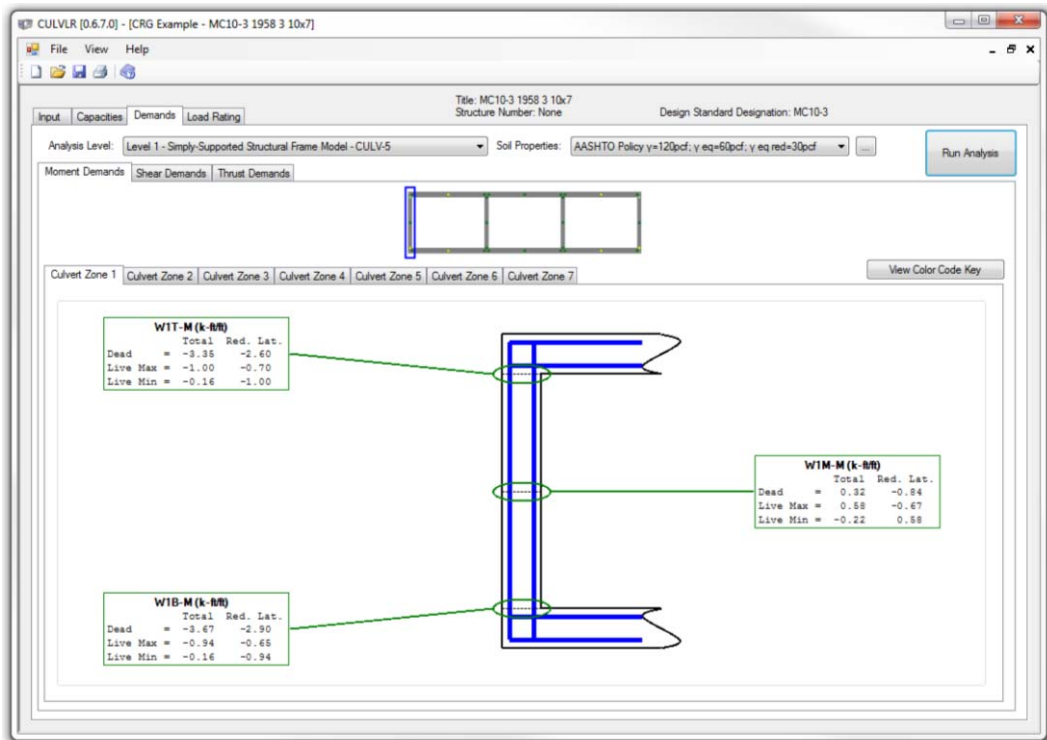


FIG. 9. Results from the demand modeling process, 'Demands' tab, CULVLR

In addition to features that allow the load rater to view the load rating input and output files, the ‘Demands’ tab summarizes calculated demands for all critical sections, by failure mode and load case, by zone. Figure 9 includes the culvert overview sketch above the detailed demand sketch to facilitate keeping track of the critical sections under consideration.

Load Rating Calculations

The ‘Load Rating’ tab, which is the final tab for the CULVLR program, is used to calculate and to present culvert load rating values based on the calculated capacities and demands, by critical section. Figure 10 presents a screen shot of the ‘Load Rating’ tab associated with the example culvert.

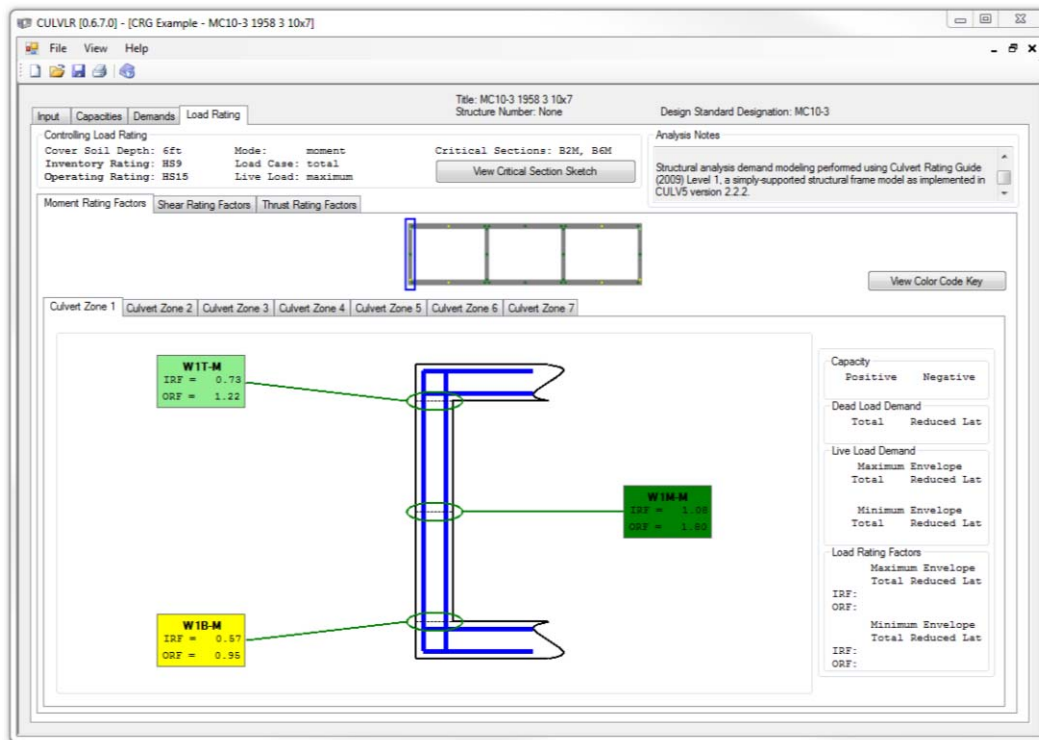


FIG. 10. ‘Load Rating’ tab, CULVLR

CULVLR presents the demands for all critical sections, by zone, for each failure mode – moment, shear and thrust. More specifically, the ‘Load Rating’ tab identifies the inventory rating factor (IRF) and operating rating factor (ORF) for each critical section. To facilitate quick review of the findings, these data cells are color-coded to match a stylized version of TxDOT’s load-posting guidance chart (Figure 11) from the TxDOT *Bridge Inspection Manual* (TxDOT 2012d).

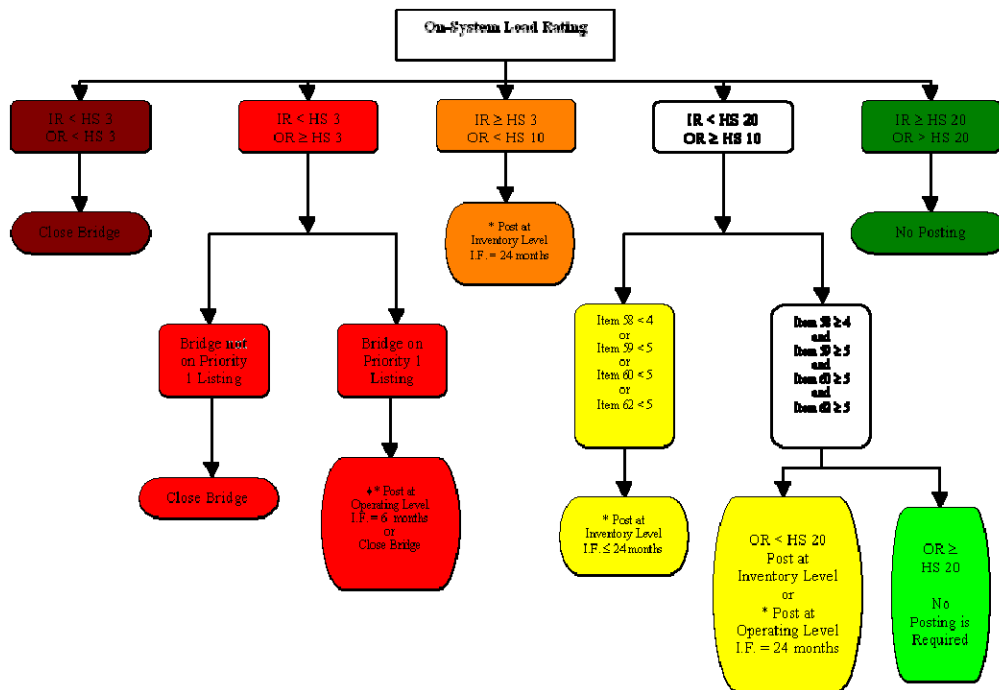


FIG. 11. On-System Load Posting Guidelines, color-coded by class, adapted from Figure 5-3, TxDOT *Bridge Inspection Manual* (TxDOT 2012).

Another interpretive feature of the CULVLR ‘Load Rating’ tab is that it presents a ‘Critical Section Sketch’ (Figure 12) with every critical section color-coded to indicate performance of the section as per the TxDOT load-posting guidance chart. This high-level presentation of the load rating data offers a quick way to assess the overall structural health of the culvert. Further, the ‘Critical Section Sketch’ specifically identifies and calls out the controlling critical section(s) for the culvert, that is, the sections with the lowest rating factor(s).

Reporting Options

As has been noted, CULVLR facilitates review of data input files and output files for the culvert rating from the ‘Demands’ and ‘Load Rating’ tabs. In addition to these in-process review and evaluation features, CULVLR includes reporting options which allow the load rater to print various types of reports that document the load rating calculations. The ‘Create Reports’ feature is accessed from the ‘File’ menu (Figure 13) or from the printer icon on the program toolbar.

Report options include summary, standard, and comprehensive reports. The summary report (Figure 14) presents the load rating results on *one* page. This report includes descriptive information about the culvert, a culvert sketch, the controlling load rating data, a critical section sketch, an analysis summary, comments block, and a place to identify the engineer(s) who performed the rating calculations.

The standard report includes the one-page summary report plus all input data. The comprehensive report provides full documentation of the load rating calculations including the one-page summary report, input data, capacities, demands, and load rating factors for all critical sections. These comprehensive reports typically number 35 or more pages.

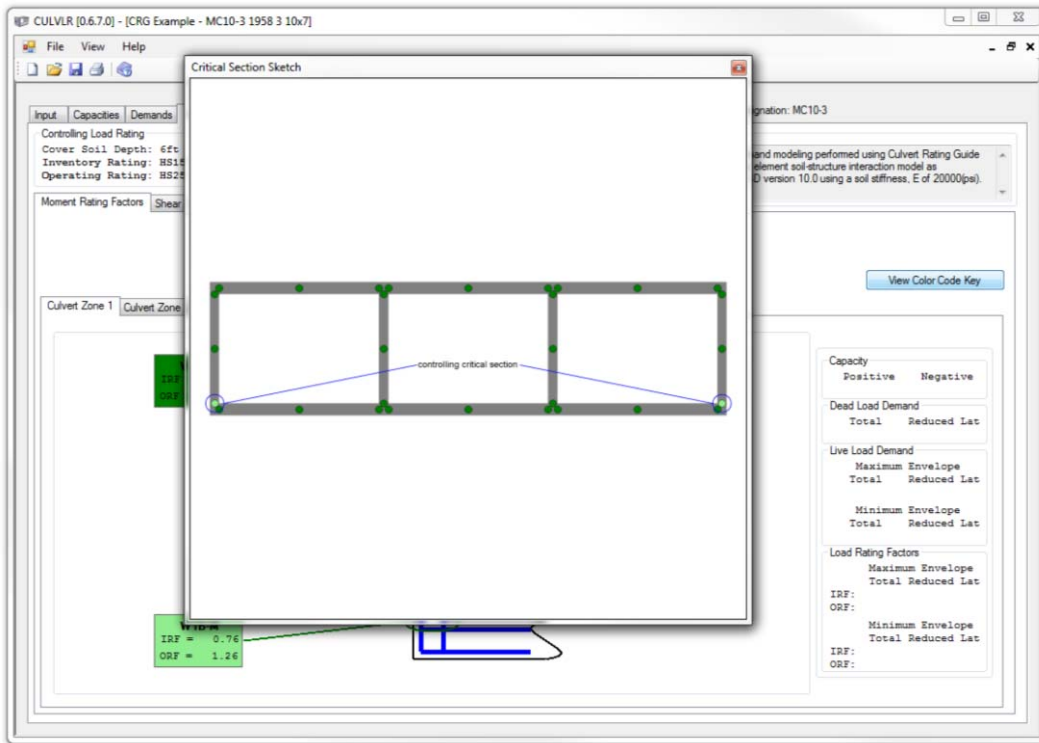


FIG. 12. 'Critical Section Sketch' from the 'Load Rating' tab, CULVLR

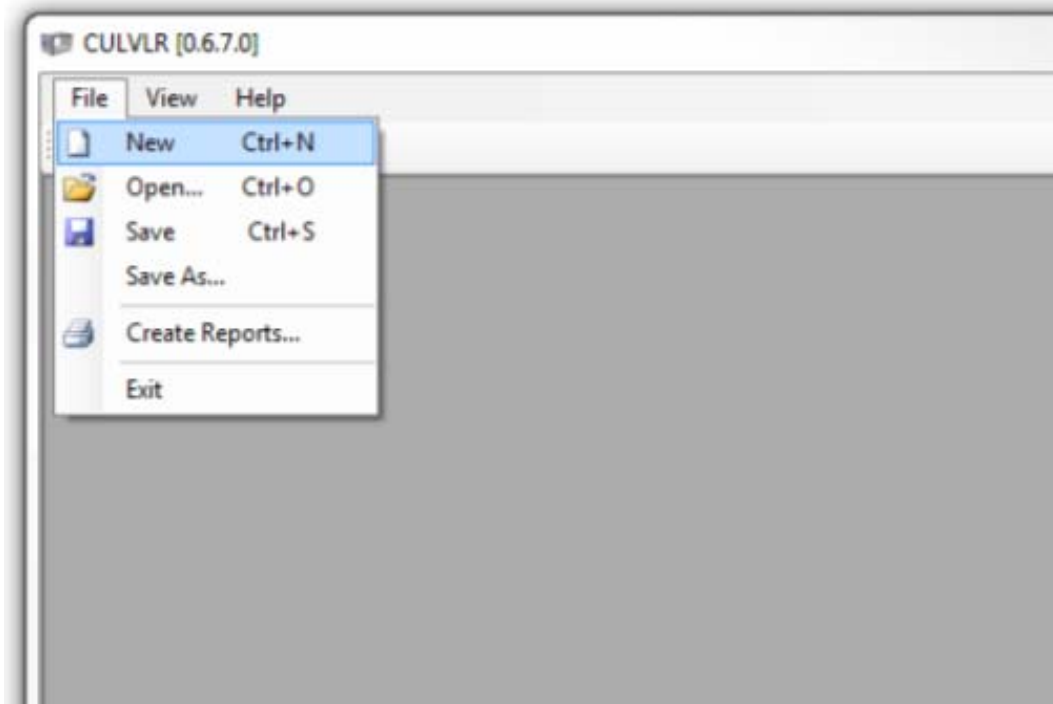
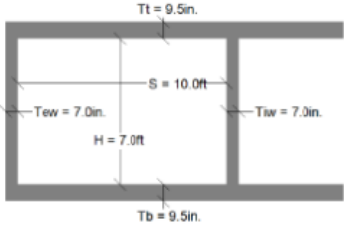
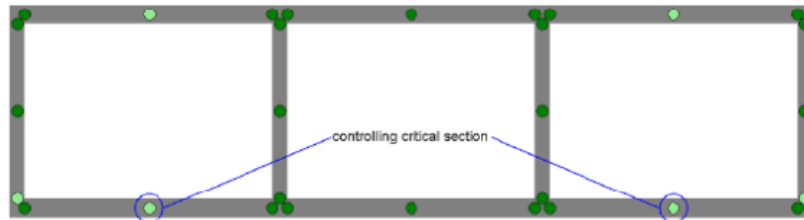


FIG. 13. Reporting features of CULVLR.

| General Information | | Culvert Sketch | |
|---|----------------------------|--|-----------------|
| Design Sheet: | MC10-3 |  | |
| Design Year: | 1958 | | |
| Steel Grade: | Gr. 40 (Fy = 40ksi) | | |
| Concrete Class: | Class A (F'c = 3000psi) | | |
| Number of Spans: | 3 | | |
| Clear Span: | 10.0ft | | |
| Clear Height: | 7.0ft | | |
| Roadway Width: | 44.0ft | | |
| Design Soil Depth Range: | 4.0-6.0ft | | |
| Soil Properties: | Policy ($\gamma=120$ pcf) | | |
| Controlling Load Rating | | | |
| Cover Soil Depth: | 6.0ft | Mode: | moment |
| Inventory Rating: | HS13 | Load Case: | reduced lateral |
| Operating Rating: | HS23 | Live Load: | maximum |
| Capacity: | | 11.422k-ft | |
| Dead Load: | | 6.260k-ft | |
| Live Load: | | 2.243k-ft | |
| Reported demand loads are unfactored. Inventory rating, operating rating and load rating factors incorporate an impact factor of 0. | | | |
| Critical Section Sketch | | | |



Refer to report 5-5849-03 narrative for key to interpreting critical section color codes.

| Analysis Summary | |
|---|--|
| <ul style="list-style-type: none"> Load rating calculations performed by the Center for Multidisciplinary Research in Transportation (TechMRT) at Texas Tech University under TxDOT implementation project 5-5849-03. Load rating calculations performed according to the TxDOT <i>Culvert Rating Guide</i> (2009) as implemented in CULVLR version 0.6.1.04. Structural analysis demand modeling performed using TxDOT <i>Culvert Rating Guide</i> (2009) Level 1, a simply-supported structural frame model as implemented in CULV5 version 2.2.2. | |
| Comments | Personnel |
| Culvert fails under dead load for all depths of fill greater than or equal to zero; no load ratings. | <i>Data Entry:</i> RM, SG, DG, ET, DLG <i>Prepared:</i> TW <i>Checked:</i> CDN, PWJ, WDL |

FIG. 14. Typical one-page summary report, CULVLR

Help Features

Load raters who are not familiar with CULVLR, or those who want to know more about a particular aspect of the culvert load rating process, will benefit from the extensive menu of 'Help' features for the program. At a basic level, CULVLR includes a complete searchable copy of the *Culvert Rating Guide*. To facilitate data entry and other load rating tasks, the Help menu presents a complete set of instructions for each tab of CULVLR in order to illustrate the data entry process. The program also includes tool tips that highlight and explain program features. These Help files are an enhancement to the program's intuitive design and make CULVLR very user friendly.

SUMMARY AND CONCLUSIONS

This implementation project developed and produced the CULVLR (Culvert Load Rating) program that automates the process by which TxDOT engineers and their consultants perform load rating calculations for reinforced concrete box culverts. Based on TxDOT's *Culvert Rating Guide*, CULVLR is designed to help load rating engineers more knowledgeably, efficiently and effectively perform the complex series of calculations necessary to establish the inventory rating and operating rating for a culvert structure.

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