TRC0303

Upgrade of the Railroad Car Bridge Analysis Software System

Thomas J. Parsons, J. David Gillanders

Final Report

2005

UPGRADE OF THE RAILROAD CAR BRIDGE ANALYSIS SOFTWARE SYSTEM

by
Thomas J. Parsons, Ph.D., P.E. and J. David Gillanders, Ph.D., P.E.
College of Engineering
Arkansas State University

CHAPTER 1
INTRODUCTION

In 1991, Arkansas State University completed the research project TRC-8901, "Evaluation of Bridges Constructed with Railroad Cars", which included a report and software programs which calculated the load capacity ratings for bridges constructed from railroad cars. The software performed a structural analysis of salvaged railroad cars and produced a bridge capacity rating. The load capacity rating and related posting are required by the Federal Highway Administration (FHWA). The report and software were operational tools used by the AHTD Bridge Division. The software was developed for a computer with a 286 processor and the Disk Operating System (DOS). Today, the software is obsolete and modern computers use the Windows 2000 Operating System. The present operating system does not support the software. As a result, bridge engineers are required to perform manual calculations to determine approximate load capacity ratings on railroad car bridges.

The objective of this study is to upgrade the load rating software to function within the Arkansas State Highway Department (AHTD) current computer operating system environment and provide the latest technology and techniques available for analyzing and calculating load ratings for bridge structures constructed from salvaged railroad cars. The deliverables for this project are pre- and post-processing software and a detailed user's manual.

BACKGROUND

The work conducted in the late 1980s and the early 1990s developed a load rating software for bridges constructed from railroad cars. No known work has been conducted on improving the existing load rating software. This study researched modern analysis tools and upgraded the software so it could operate in a Microsoft Windows format and be usable on the AHTD server or network.

CHAPTER 2

LOAD RATING PROGRAM

The load rating software program was designed to produce a load rating for an individual railroad car. The first part of the load rating program consists of developing a finite element command file from the field data collected during field inspections of railroad car bridges. The field data consists of the longitudinal and cross beams spacing, beam type and the geometry of each beam. The software writes the required command file including unit truck loadings. The

unit truck loadings represent inventory and operating vehicles. The dead load on the bridge deck is also entered.   The command file is loaded into a finite element software package and the resulting beam forces and moments are determined. A separate spread sheet is activated which reads the results from the finite element analysis and determines the bridge load rating for each type of vehicle.   The load rating is determined by calculating the maximum moment each bridge member or beam can produce at failure loadings. The dead load and self weight moments are subtracted from the failure moment to produce a net moment. The net moment is divided the resulting moments produced by the unit truck loadings in order to determine the bridge load rating for each type vehicle.

DATA ENTRY FORMAT

Data entry is based on the information that would be obtained from the field inspection of the bridge. It consists of the spacing between the cross beams, which include end beams, cross ties, floor beams and the bolster. The spacing between the longitudinal beams is also required. These beams include the outer side sill, inner side sill, stringers and center beam. The beam structural properties are determined by entering the physical dimensions of the beams.   The physical dimensions are entered into pre-selected beam shapes and the physical properties of the beam are determined. The beam shapes that are included in the program include channels with and with out lips, hat shapes, box shapes, "I" sections, angles and "Z" shapes. The beam spacing can be entered in feet or inches. The beam dimensions are entered in inches. Other data entry includes the dead load on the bridge deck.

The data entry required for the operation of the software program includes the following:

1. Name of Engineer
2. Bridge or car ID number
3. Car length and width
4. Number of cross beams including end beams.
5. Number of longitudinal beams.
6. If two cars are used to form the bridge, the spacing between the cars
7. Distance between cross beams and type of cross beams; that is, either a bolster, floor beam, or cross tie.
8. Distance between longitudinal beams and type of longitudinal beam; that is outer side sill, stringer, center sill and inner side sill.
9. The number of reduced height longitudinal beams at each end of the bridge for the side sills and center sill.
10. If the floor beams have diagonal bracing made from angles.
11. For each type of beam entered into the program, the shape of the beam and the corresponding dimensions.
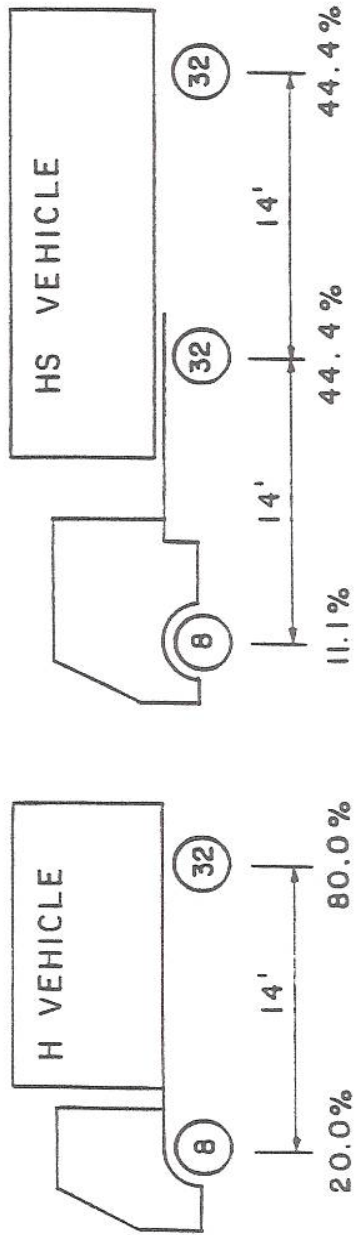12. The deck dead load in pound per square foot.

PROGRAM FUNCTION

The software program generates the finite element command file needed to determine the forces and moments in the railroad car beams. The STAAD finite element software package was chosen to perform the structural analysis on the bridge or railroad car. The software program uses the field data entered to generate the number of finite element node points and the corresponding coordinates for each node point. Next, the cross beam element indices are determined followed by the longitudinal beam element indices. This includes the extra elements generated if the floor beams have diagonal braces. When the floor beam has diagonal braces an extra node is added along with three elements for each floor beam. One element is a vertical element under the center sill with a length equal to the height of the center sill. The other elements are the two diagonal bracing elements. For each type of element the sectional properties are calculated. The properties include the element cross section end area, vertical and horizontal shear area, moment of inertia about the strong and weak axis and the torsional constant. Several load cases are determined and generated. These load cases include unit trucks for the inventory and operating vehicles and the bridge deck dead load. STAAD is designed so it can handle several load cases at one time. For each load case entered into STAAD the corresponding element forces and moments are determined.

Program Unit Truck Loads

Several load cases are developed and entered into the STAAD command file. These load cases include the inventory vehicles, operating vehicles and bridge deck dead load. A unit vehicle or truck load is developed for each inventory and operating vehicle. The unit vehicle has a weight of one ton. Point loads are placed on the longitudinal elements which represent the individual wheel loads corresponding to each type of vehicle. The wheel loads are based on the axle weight percentages given for each vehicle in Figure 1. The inventory vehicles include the "H" and "HS" vehicles. The operating vehicles include the "T3", "T4" and "T3S2" vehicles. The center of gravity of each vehicle is placed at the center of the car or bridge span. The vehicle is then placed centered on the car or bridge with respect to the width of the car or with the vehicle positioned as if one side of the vehicle or set of wheels would be driving over the inner side sill. If the wheel load fell between two longitudinal beams, point loads were placed on both beams proportioned as to the spacing between beams. A load case representing a one ton single axle is also developed. The axle is placed over the cross tie closest to the center of the span and connecting to the inner side sill.
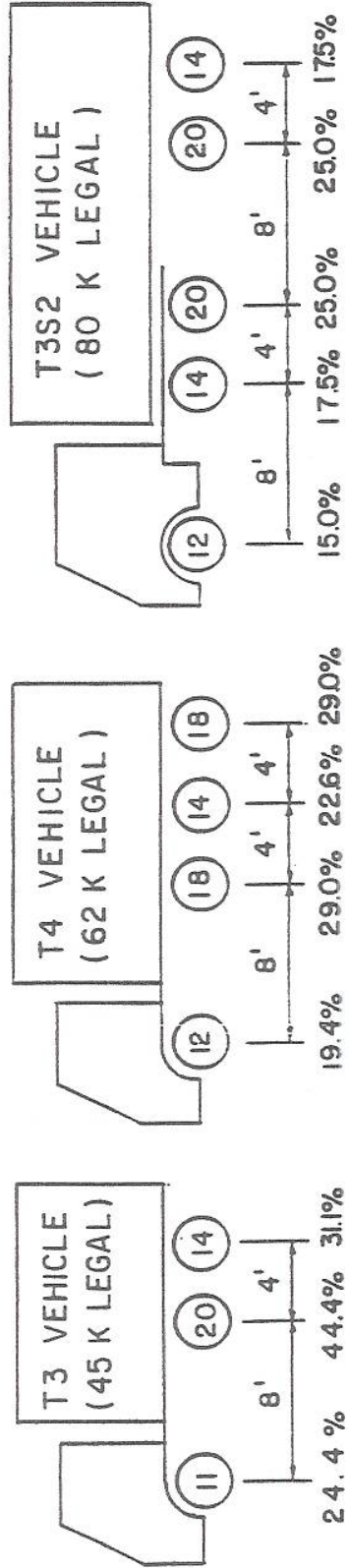
INVENTORY VEHICLES

H VEHICLE

(8) — 14' — (32)

20.0%   80.0%

HS VEHICLE

(8) — 14' — (32) — 14' — (32)

11.1%   44.4%   44.4%

OPERATING VEHICLES

T3 VEHICLE (45 K LEGAL)

(11) — 8' — (20) — 4' — (14)

24.4 %   44.4%   31.1%

T4 VEHICLE (62 K LEGAL)

(12) — 8' — (18) — 4' — (14) — 4' — (18)

19.4%   29.0%   22.6%   29.0%

T3S2 VEHICLE (80 K LEGAL)

(12) — 8' — (14) — 4' — (20)   (20) — 8' — (14) — 4' — (14)

15.0%   17.5%   25.0%   25.0%   17.5%

Figure 1 Inventory and Operating Vehicles

The dead load on the bridge deck is modeled by placing a uniform member load on the longitudinal beams. The intensity of the load is determined by the magnitude of the dead load in

pounds per square foot and the spacing between longitudinal beams. The magnitude of the uniform load is equal to the dead load intensity times the sum of one half of the spacing between longitudinal beams. One half of the spacing between cars is used in the calculation of the inner side sill uniform load intensity. The beam self weight is treated as a separate load case. The load cases are written in the STAAD command file in the following order:

1. Self weight
2. Dead load
3. "H" Truck center
4. "H" Truck over the inner side sill
5. "HS" Truck centered
6. "HS" Truck over the inner side sill
7. "T3" Truck centered
8. "T3" Truck over the inner side sill
9. "T4" Truck center
10. "T4" Truck over the inner side sill
11. "T3S2" Truck centered
12. "T3S2" Truck over the inner side sill
13. Unit axle load

STAAD Command File

The STAAD command file includes joint coordinates, element indices, material properties of steel with the steel yield strength at 36 ksi, member properties, simple supports at one end and roller at the other end of the bridge or car and the 13 load cases. The program is instructed to determine the member forces and moments for each element.

DATA ENTRY

The data entry is represented by the following screens. An explanation of the data entered for each screen is given along with procedures on how to change the data entered if an error is made during the entry.

Screen 1

The name of the person doing the data entry should be entered in the text box labeled "Engineer". In the box labeled "Bridge and Car ID" the bridge number should be entered. The entry in this box will be used to create the name of the STAAD command file. The name of the STAAD command file is written as "Bridge" followed by the data entry, followed by ".std". The bridge length and width are entered in the next two lines of input boxes. This data is only used as a check. The distance between beams is summed and compared to the entered distance. The number of cross beams is entered in the next box. This number will include the end positions as a beam even if there is no actual beam present. Then the number of longitudinal beams is entered in the following box. The last data entry is the spacing between cars on bridges two railroad cars wide. This spacing is only used in the modeling of the dead loads on the bridge. If the bridge is a single car bridge, the spacing should be zero. The check data key checks for a valid entry in all data entry boxes. The data may be changed any time prior the clicking on the **Check Data** button. When all data is correct click the **Check Data** button. If errors are found, the error will be highlighted. A correction can then be made. After making corrections, click the **Check Data** button again. Then click the **Go to Cross Beams Positions** button.

Screen 2

The first data entry is the type of end beam at the start of the car. The code numbers for each type of cross beam is shown in the upper right corner of the window. Only code numbers 0 to 4 may be entered in this screen. If the car has been cut and no cross beam is present enter 0 or "No Beam at this position". This may also be done at the far end of the bridge. Click the **Next Beam** button and the window will then show the text boxes for the beam spacing between beams and the next beam number. Enter the center to center spacing between beams and the type of the next beam. Data may be changed at any time up to the time the **Next Beam** button is clicked. Repeat this process until all cross beam data is entered.

The **Check Entries** button and the **Go to Longitudinal Beam Positions** button will appear after the last beam has been entered. If the sum of the beam spacing is different from the given length of the bridge by more than 0.1 feet, an error message box will appear. Click **OK** in the message box and then the **Check Entries** button to step through the cross beam data and make corrections where required. If the "Total length so far" display and the "Overall length given" are close enough you may skip the checking if desired. When all data entry is complete and correct click the **Go to Longitudinal Beam Positions** button.

Screen 3

The first data entry is the type of side sill on the outside edge of the car. The code numbers for each type of longitudinal beam is shown in the upper right corner of the window. Only code numbers 0 and 5 to 8 may be entered in this screen. Click the **Next Beam** button and the window will then show text boxes for the spacing to the next beam, followed by the next beam number. Enter the center to center spacing between beams and the type of the next beam. Data may be changed at any time up to the time the **Next Beam** button is clicked. Repeat this process until all longitudinal beam data is entered.

The **Check Entries** button and the **Go to Sectional Properties** button will appear after the last beam has been entered. If the sum of the beam spacing differs from the given width of the bridge by more than 0.1 feet, an error message box will appear. Click "OK" in the message box and then you can use the **Check Entries** button to step through the longitudinal beam data and make corrections where required. If the "Total width so far" display and the "Overall width given" are close enough you may skip the checking if desired. When all data entry is complete and correct, click the **Go to Sectional Properties** button.

Screen 4
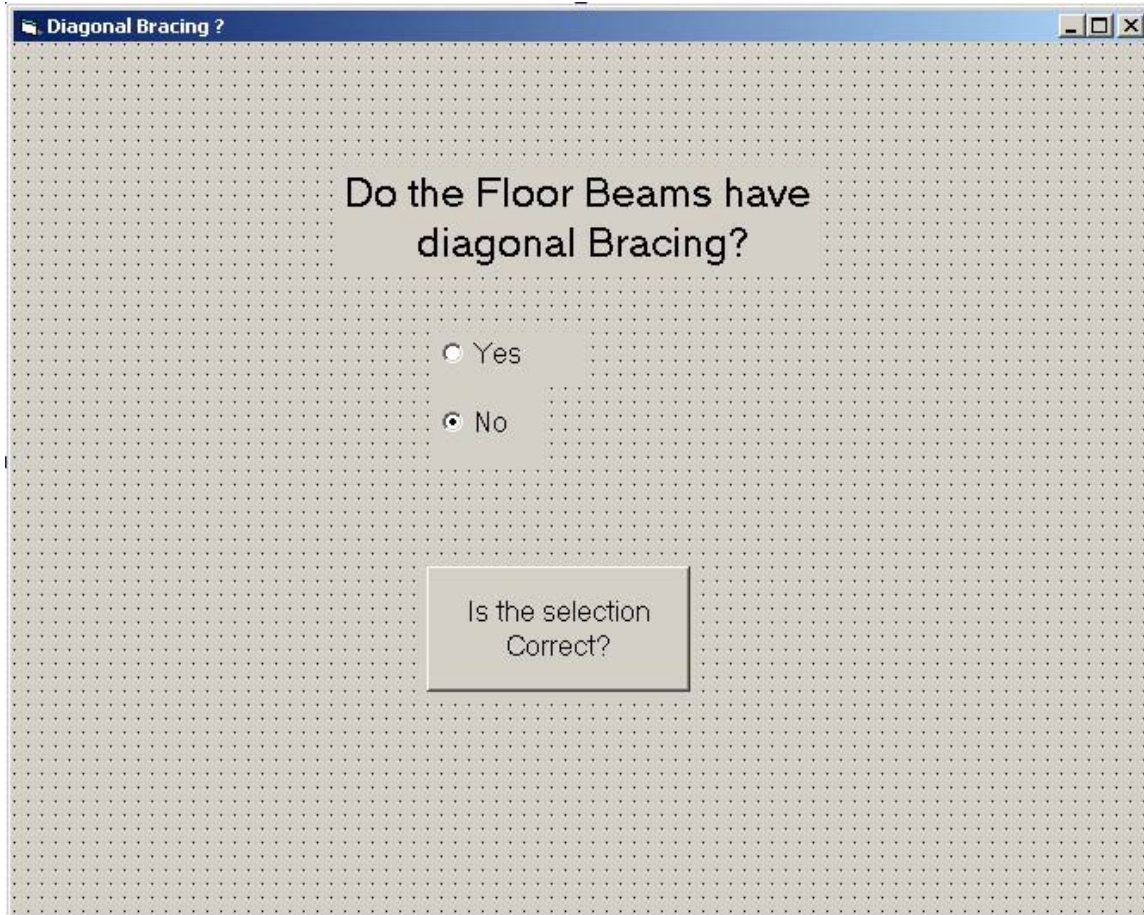
This screen is used to indicate which side sill and center sill elements have a reduced height near the ends of the car. The reduced heights are first entered outer side sill, then the center sill, then the inner side sill. The side sills and center sill is divided into segments or elements corresponding to the spacing between cross beams. Enter the number of these segments at each end of the car that have a reduced height. Then click the **Is this correct?** button. If all three beams have the same number of reduced segments, the data only has to be entered the first time, but the **Is this correct?** button must be clicked for each longitudinal beam.

Screen 5

Click "Yes" if the Floor Beams have diagonal braces. Then click the **Is this Selection Correct?** Button to continue. If the floor beams do not have diagonal braces, click the "No" and then the **Is this selection Correct?** button to continue.

Screen 6

This screen will request information on the geometric shape and corresponding dimensions for each beam type that has been selected in the data entry. The screen will automatically scan through beam types entered. The beam type will appear on the second line of the window. Choose one of the eight given shapes that best describes the geometry of the beam. Click on the corresponding button and the data entry window will appear for that shape. Enter the requested physical dimensions for the selected shape. The data can be corrected in the window at any time up until the **Calculate** button is clicked. If the window with the beam shape and request for physical dimensions is not the correct shape, click the **Cancel** button and the original window will return. You may then make another selection of beam shape. After clicking the **Calculate** button the above screen will reappear with the calculated sectional properties displayed. At this time, the beam physical properties may be change by clicking on a beam shape button and re-entering the corresponding data. This may be repeated until the **Next Beam Type** button is clicked. If the results are acceptable click on **Next Beam Type** button and repeat the process until all beams types have been completed.

The beam shapes windows and data entry requests are as follows.
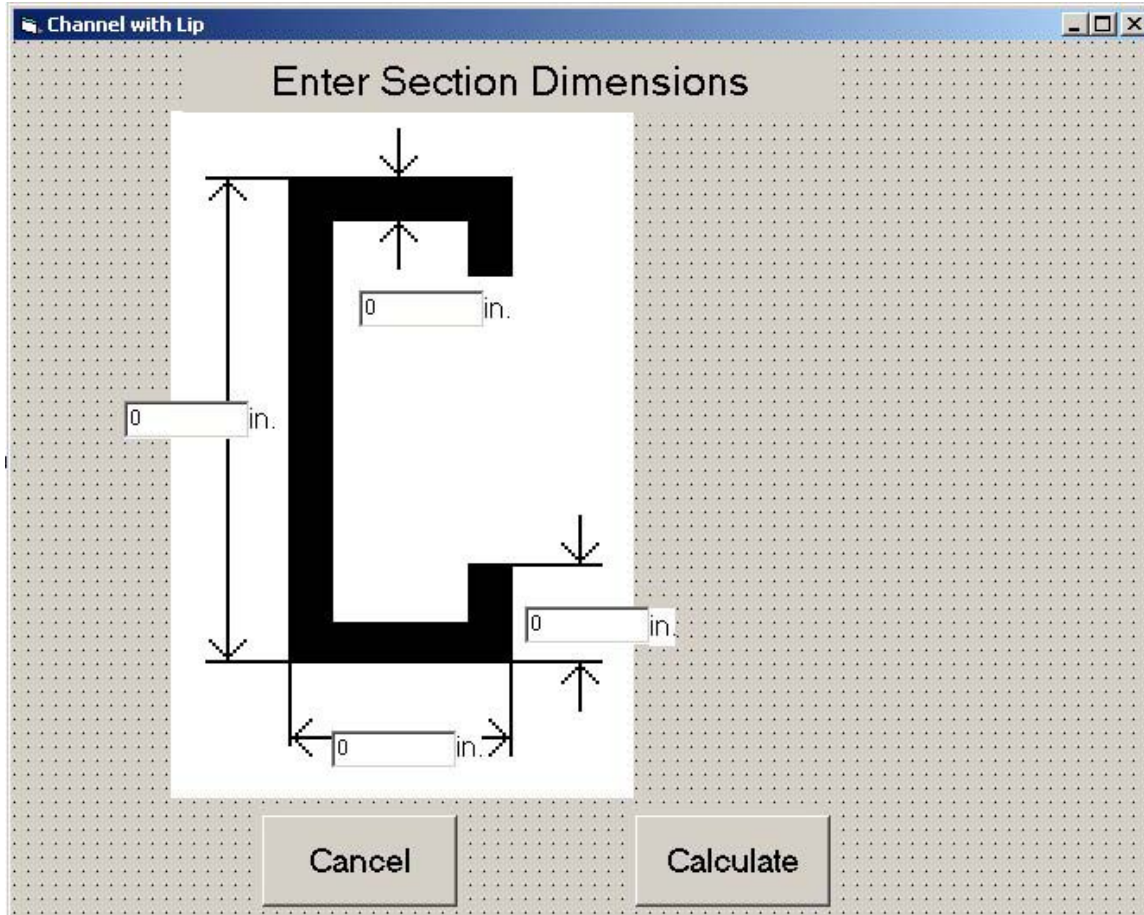
Screen 6a - Angle

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. The beam can be rotated by selecting the "Rotate Clockwise 90 Degrees" mode. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6b - Box Shaped Beam

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6c – Channel Section

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. The beam can be rotated by selecting the "Rotate Clockwise 90 Degrees" mode. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6d – Channel Section with Lips

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6e – Double "I" Center Sill

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6f – Hat Shaped Section

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 6g – "I" Section

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.
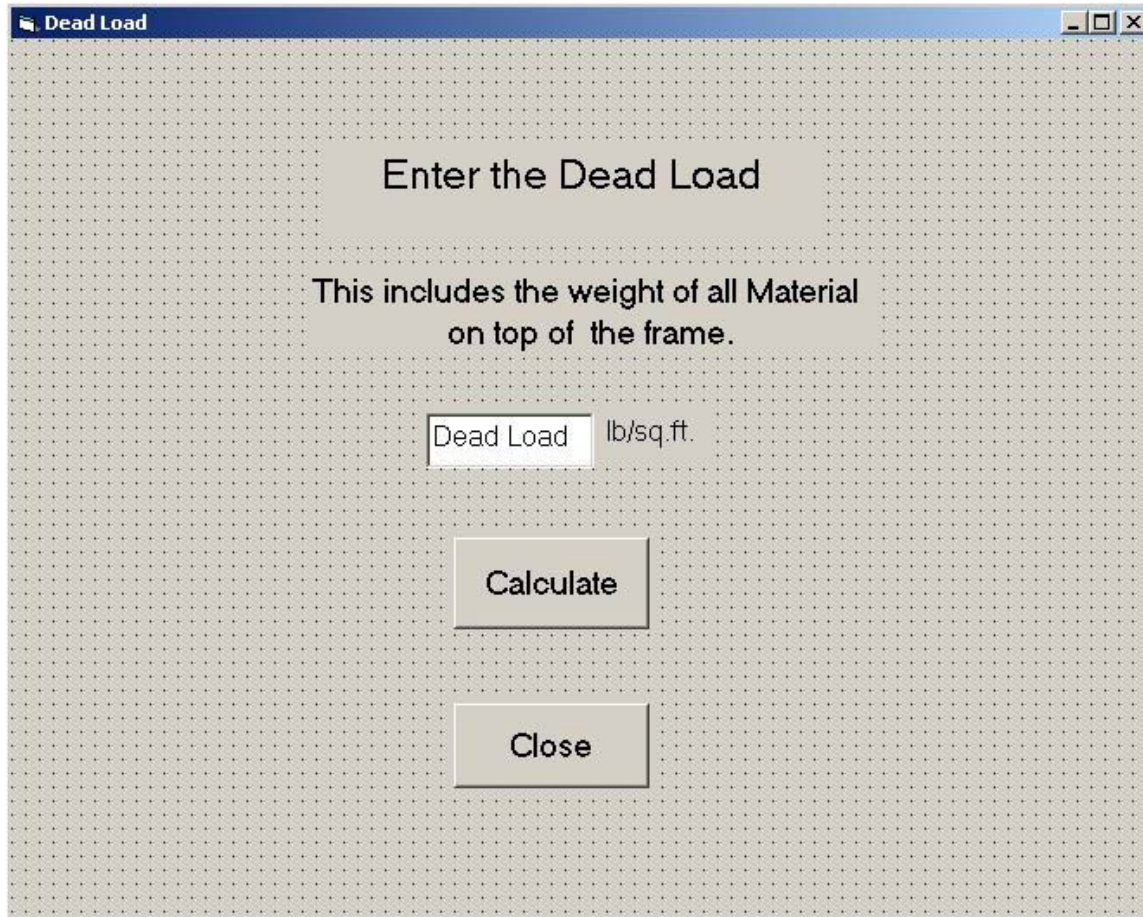
Screen 6h – "Z" Section

The requested physical dimensions are entered in inches. Enter the data and press the tab key to proceed to the next data entry point. Corrections may be made at any time until the **Calculate** button is clicked. Use the mouse to select the data entry point for correcting the data. Press the **Calculate** button to enter data for the next beam. The **Cancel** button would return to the previous window.

Screen 7

In this window the dead load is entered. This load accounts for the effect of the bridge deck being loaded with gravel, concrete, or asphalt overlays. The data is entered in pounds per square foot. After pressing the calculate button, a uniform load is calculated written to the STAAD command file. A message will appear saying that the STAAD file has been written and a **Close** button will appear. Click the **Close** button to terminate the program.

STAAD Analysis

Upon completion of the data entry, STAAD must be run to analyze the structure. The following procedure is used to run STAAD. The STAAD file will be written into the directory containing the data entry program. Activate the STAAD software and locate the STAAD command file. This file will have the name "Bridge" followed by the number you entered into the first screen of the data entry program, followed by ".std." Windows will display this file as a STAAD Space Frame file type. After STAAD is activated go to "File", open and locate the STAAD file that contains the selected bridge number, press "Finish" to load the file into STAAD. To perform the analysis, press the "Analysis" button at the top of the screen, then press the "Run Analysis" button on the drop down menu. Then click "Run Analysis" on the next window that opens.

After the analysis is completed click the "Done" button on the new window. To finish the load rating program you must run the Excel spread sheet.

CHAPTER 3

EXCEL LOAD RATING PROGRAM

The Excel "Load Rating Program" reads the force and moment output file generated by STAAD and calculates the bridge truck load rating for the different type of operating and inventory trucks. The spreadsheet uses OPEN STAAD micros to obtain the maximum and minimum moments associated with each element.

The spreadsheet is set up to calculate the bridge rating in two modes, the ASD mode or the LRFD mode. The mode is selected by the entry of the "Allowable Stress Factor"; "Dead Load Factor F1"; and the "Live Load Factor F2". The ASD mode is obtained by setting the Allowable Stress Factor to 0.67 and the Dead and Live Load Factors to 1.0. The LRFD mode is set by setting the "Allowable Stress Factor" to 0.90, "Dead Load Factor" to 1.2 and the Live Load Factor to 1.6.

To calculate the bridge load rating the following procedure is used. The spreadsheet obtains each element's physical properties and calculates the "Element Allowable Moment" for each element. The "Element Allowable Moment" (Ma) is obtained by the following equation:

Ma = ("Allowable Stress Factor" x 36 ksi) x (major axis moment of inertia) / (beam height / 2)

The bridge load rating for each type of truck is calculated for each element by subtracting the dead load and self weight moments times the dead load factor from the "Element Allowable Moment" for each element. This value is divided by the moment produced by the unit truck loads multiplied by the Live Load Factor to obtain the truck load rating. This is repeated for each type and position of unit truck. The load ratings are stored in the Excel spreadsheet by element number. For each element a truck load rating is produced based on the minimum and maximum moments for each truck load case. The truck load rating for each type and position of truck is produced by searching each element for the minimum load rating. The results are stored in the blue highlighted area of the spreadsheet. The overall bridge load rating is produced by searching the truck load rating for the minimum truck load rating.

ACTIVATION OF EXCEL LOAD RATING PROGRAM

First activate Microsoft Excel and open the file "RR Bridge Rating". The following screen will appear.

Write the name and path of the STAAD file in Cell B2

Directory	C:\AHTD 23 June 2004
Bridge Number	19896

To Run press "Ctrl+Shift+R"

Regsvr32 openstaad.dll

Allowable Stress Factor =	0.67
Dead Load FactorF1 =	1
Live Load FactorF2 =	1

In the highlighted cell labeled "Directory" enter the directory name for the STAAD file. In the cell labeled "Bridge Number" enter the same number you entered in the original data entry program. Enter the "Allowable Stress Factor", "Dead Load Factor", and "Live Load Factor." The default mode is the ASD mode. Then press CTRL+Shift+R to run the rating macro. The output will appear as follows.

Max Load(tons)											
	Truck Unit Load Cases										
Overall	H-Truck		HS-Truck		T3-Truck		T4-Truck		T3S2-Truck		Max
Max	Center	Edge	Center	Edge	Center	Edge	Center	Edge	Center	Edge	Axel
7.492709	7.49270903	7.921385	24.23695	24.06549	24.3804	24.23472	19.86784	21.27959	22.05612	23.18032	13.73187

The overall bridge load rating along with the individual bridge load rating for each type of vehicle are given in the blue highlighted area of the spreadsheet.