Load Rating of Single Span, Glulam Beam Bridges using Two Computer Applications

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Abstract

The National Bridge Inspection Standards requires bridges be inspected biannually and when conditions warrant that a load rating must be conducted. There are more than 575 thousand bridges in existence today. As these structures age, load rating should be conducted when a significant change in condition occurs. Load ratings are time consuming and costly. With ever decreasing maintenance budgets, an economical and versatile load rating worksheet or a computer program would be of benefit to many local, state and federal agencies. With the broad availability of computers, this process can be accomplished quickly and accurately with computer spreadsheets or programs. This paper will discuss two different computer programs developed to load a rate single span, one lane, glulam beam bridges for a standard AASHTO HS20 vehicle.

The two methods developed, used a Mathcad® 6+ worksheet and a QuickBASIC program to calculate load ratings for a Glulam Beam bridge. Mathcad® 6+ is a powerful mathematical tool that allows equations to be written in both real math notation and in a worksheet. Two additional functions were developed for calculating moments and shears using a Dynamic Linked Library (DLL) in Mathcad® 6+. QuickBASIC is a computer language that is widely used and is easy to learn.

The single span, one lane bridge type was used because it is standard type structures for the U.S.D.A. Forest Service and many local municipalities. Alterations may be made with ease for load rating other bridge types and multiple lane structures. Load rating bridges using a Mathcad® 6+ worksheet and a QuickBASIC program turned out to be a very economical and viable solution for this bridge type.

Load Rating

The load rating procedure used in this paper will follow the method detailed in the Manual for Condition Evaluation of Bridges, 1994 and the standard design specifications from AASHTO Standard Specifications for Highway Bridges, 15th ed. Load rating involves structural inspection and calculations based, in part, on inspections of the structure. Structure inspection should comply with the requirements of the National Bridge Inspection Standards with respect to frequency of inspections, type of inspections and qualifications of inspection personnel. The types of inspections are initial, routine, damage, in-depth and special. The normal frequency for routine inspections is biannual with additional inspections being conducted when the structure has been damaged or when conditions suggest a more in-depth inspection be needed. Load ratings should be conducted for damage, in-depth and special inspections and for routine inspections, when changed conditions warrant it. The Manual for Condition Evaluation of Bridges, 1994 states the qualifications for "the individual charged with the overall responsibility for load rating bridges should be a licensed professional engineer and preferably have a minimum of five years of bridge design and inspection experience." They should also have experience and knowledge with the type of bridge that is to be load rated.

Structures should be load rated for inventory and operating levels. Inventory rating is the stress level at which the bridge was designed and the live load that can safely use the structure for an indefinite period or indefinite repetitions. Operating rating is the stress level at the maximum permissible live load that the bridge may be subjected, but allowing unlimited vehicles at this stress level may shorten the bridge life. Use of the bridge at operating stress level requires the governing agency to issue special use permits for that vehicle.

Rating Procedure

This paper follows the rating procedure outlined in Section Six (6) of the Manual for Condition Evaluation of Bridges. 1994 published by the American Association of State Highway and Transportation Officials. This procedure only addresses ratings of interior beams.

Nomenclature

The following nomenclature will be constant for the worksheet and program:

A- Area

A_v- Area for shear.

A_T- Total area of beam.

Bridge_Span - Span of bridge in feet. Measured from the centerline of bearing to the centerline of bearing.

C_M- Moisture content factor.

C_D- Duration of load factor.

C_f- Form factor.

C_V- Volume factor.

C_L- Lateral stability of beams factor.

DL_{Deck}- Dead load due to deck.

DL_{Beam} - Dead load due to Beam.

$DL_{RunningSurface}$- Dead load due to running surface.

DL_{Total} - Total dead load.

F'_b - Allowable bending stress.

F'_V- Allowable shear stress.

F_b - Tabulated bending stress.

Fv - Tabulated shear stress.

Inv_Rating - Bridge member rating in tons for inventory stress level.

I_X - Moment of Interia

M_{R_inv} - Moment Capacity of the member for inventory stress level.

M_{R_oper} - Moment Capacity of the member for operating stress level.

M_{DL} - Moment due to dead load.

M_{LL} Moment due to live load.

Num_of_Beams - Number of glulam beams.

Oper_Rating - Bridge member rating in tons for operating stress level.

R_{DL}- Reaction due to dead load.

RF- Rating factor for the live load carrying capacity with subscripts for a combinations of moment, shear, inventory and operating.

S_x- Section Modulus

$V_{R\text{-}inv}$- Shear Capacity of the member for inventory stress level.

V_{R_oper}- Shear Capacity of the member for operating stress level.

V_{DL}- Shear due to dead load.

V_{LL}- Shear due to live load.

Wt_{Wood} - Weight of wood, 50 lb/ft^3.

b - Width of beam.

$b_{Reduction}$ - Reduction in beam width.

$b_{Effective}$ -Effective beam width.

d - Depth of beam.

$d_{Reduction}$ - Reduction in beam depth.

$d_{effective}$ - Effective beam depth.

Allowable Stresses

Table 13.5.3A Structural Glued Laminated Softwood Timber of AASHTO Design Specifications gives the allowable stresses.

Dead Load

The dead load is the weight of the member and any other permanent weight carried by the member. The unit weights for materials in this calculation follow AASHTO 3.3 Dead Load. Use a weight of wood is 50 lb/ft^3.

Live Load

The live load is the weight of a moving vehicle that is traveling across the bridge. The typical vehicle used in these load rating worksheets is a standard AASHTO HS20 vehicle per Manual for Condition Evaluation of Bridges, 1994. Mathcad® 6+ functions were developed for calculating maximum moment and shear using mvldStdMaxM(span, type) to calculate the maximum moment and mvldStdMaxV(span, type) to calculate the maximum shear for any simple span length due to five vehicle types. Span is the clear length of bridge in feet. The QuickBasic program calculates the maximum moment and shear using a program subroutine. Any of the following five vehicles maybe used to load rate the bridges:

(1) Standard AASHTO HS20 Vehicle

(2) Standard Forest Service U54 logging truck
(3) Standard Forest Service U80 logging truck
(4) Standard Forest Service U102 logging truck
(5) Standard Forest Service L90 yarder

The programs compute the live load shear at a distance three times the beam depth or the quarter point, whichever is less. A shear envelope approach is used to approximate the shear at this point.

Distribution of Live Load

The distribution of live loads to individual stringers is determined by AASHTO 3.23 Distribution of Loads. The column labeled Bridge Designed for One Traffic Lane from Table 3.23.1 Distribution of Wheel Loads in Longitudinal Beams was used for calculation of live load distribution for Glulam Bridges. The distribution of live load shear follows AASHTO 13.6.5 and the given formula:

$$V_L=0.5*[(0.6*V_{Lu})+V_{LD}]$$

where V_{LL} is the distributed live load vertical shear, V_{LU} is the maximum vertical shear from an undistributed wheel line, and V_{LD} is the maximum vertical shear from the vehicle wheel lines distributed laterally as specified for moment.

Impact Factor

Timber structures do not require an Impact Factor (I).

Rating Formula

The Rating Factor (RF) equation (6-1a) for Allowable Stress Design is

$$RF=\frac{Member\ Capacity-\ Member\ Dead\ Load}{Member\ Live\ Load*(1+Impact\ Factor)}$$

where the load effect being the effect of the applied loads on the member. The bridge rating equation (6- lb) is

$$Bridge\ Member\ Rating=\ RF*\ Nominal\ Weight$$

with the bridge member rating and nominal weight in tons. The lowest rated structural member controls the load rating of the bridge. This worksheet rates interior beams for shear and bending. Other elements of this bridge such as decking and substructure need rating.

Mathcad® 6+ and DLL'S

Mathcad® 6+ computer software allows placing of formulas, numbers, graphics and text into a worksheet, that is easy to follow and professional in appearance. The equations are shown in real math notation and the changing of variables update answers instantly. Modifying equations is simple and results are obtained on the spot.

Mathcad® 6+ supports Dynamically Linked Libraries (DLL's), development of customized functions, which simplify Mathcad® 6+ worksheets. These functions are included as a built-in function in Mathcad® 6+. One DLL developed for the load rating worksheets, contained two functions: mvldStdMaxM(span, type) and mvldStdManV(span, type). MvldStdMaxM(span, type) stands for the Maximum Moment due to Standard Moving Loads. The function calculates the maximum moment of a single span beam due to standard moving vehicles. MvldStdMaxV(span, type) stands for the Maximum Shear due to Standard Moving Loads. The function calculates the maximum shear of a single span beam due to standard moving vehicles. The span is the clear span of the bridge and type is either 1 - AASHTO HS20 truck, 2 - Forest Service U54 logging truck, 3 - Forest Service U80 logging truck, 4 - Forest Service U102 logging truck or 5 - L90 yarder.

The procedure for developing a DLL is relatively simple and requires Mathcad® 6+ and a 32-bit C++ compiler. The steps in creating a DLL are 1) writing the source code in C or C++, 2) compiling the source code with a 32-bit compiler, 3) linking the object files with the **mcaduser.lib** file to create a DLL, and 4) placing the DLL in the directory **C:\mcad\userefi.** Mvldstd.dll is the name of the DLL created. Mathcad® 6+ allows for error checking in the DLL and will return user friendly error messages. The errors checked for in the above DLL are: 1) span must be positive, 2) span must be real number and 3) type must be 1,2,3,4 or 5. See Figures l-4 for an actual Mathcad® 6+ worksheet.

QuickBasic Program

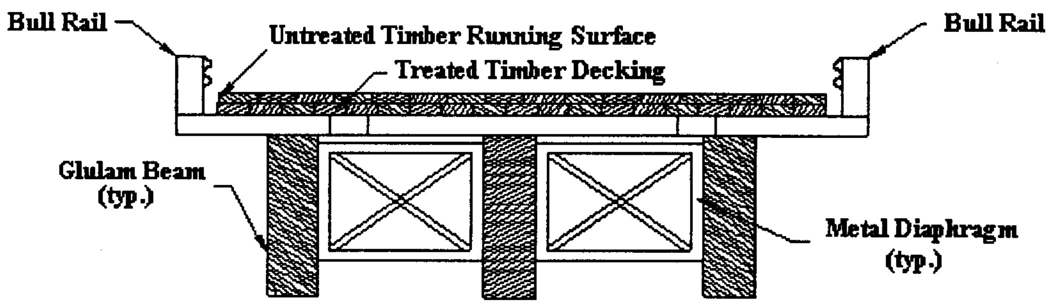
The basic program discussed in this paper was developed by Charles Milne, PE for the Stikine Area of the Tongass National Forest. The program was written in a computer language called basic and was developed for a specific bridge type. The program has tried to take into account most of the major attributes for load rating glulam bridges. A subroutine was written for calculating a maximum moment and shear for the five types of vehicles listed above. See Figure 5 for an actual QuickBasic program output.

GLULAM BEAM BRIDGE RATING

The following program rates single span, one lane Glulam bridges using the procedure described in the Manual For Condition Evaluation of Bridges published by the American Association of State Highway and Transporation Officials, 444 North Capital Street, N.W., Suite 249, Washington, D.C. 20001. This worksheet considers interior stringers only.

General Information

Bridge_Span := 48 in feet. Measure from center to center of bearing. kips := 1000·lb



Treated Timber Glulam Bridge Typical

$d := 50.875 \cdot in$ $b := 8.5 \cdot in$ Num_of_Beams := 3 $S_{Beam} := 5.68 \cdot ft$ $Wt_{Wood} := 50 \cdot \frac{lb}{ft^3}$

$d_{Reduction} := 0 \cdot in$ $b_{Reduction} := 0 \cdot in$ $t_{Plank} := 6.75 \cdot in$ $t_{Running\_deck} := 4 \cdot in$

Section Properties

$b_{Effective} := b - b_{Reduction}$ $b_{Effective} = 8.5 \cdot in$ $d_{Effective} := d - d_{Reduction}$ $d_{Effective} = 50.87 \cdot in$

$I_x := \frac{b_{Effective} \cdot d_{Effective}^{3}}{12}$ $I_x = 93271.93 \cdot in^4$ $S_x := \frac{I_x}{\left(\frac{d_{Effective}}{2}\right)}$ $S_x = 3666.71 \cdot in^3$

$A_V := (b - b_{Reduction}) \cdot (d - d_{Reduction})$ $A_V = 432.44 \cdot in^2$

$A_T := b \cdot d$ $A_T = 432.44 \cdot in^2$

Allowable Stresses

from AASHTO Table 13.5.3A for Structural Glued Laminated Softwood Timber

$F_b := 2400 \cdot \frac{lb}{in^2}$ $F_v := 200 \cdot \frac{lb}{in^2}$

Moisture_Condition := 1 1 for Wet Use & 0 for Dry Use

C_{mv} := if(Moisture_Condition=1, .875, 1) $C_{mv} = 0.875$

(AASHTO 13.5.4.1)

C_{mb} := if(Moisture_Condition=1, .8, 1) $C_{mb} = 0.8$

$C_D := 0.9$ (AASHTO 13.5.4.2)

$C_f := 1.0$ (AASHTO 13.6.4.5)

Figure 1-Page 1 of 4 of Mathcad® 6+ Worksheet

$x \equiv 10$ for all other species $x \equiv 20$ for Southern Pine

$$C_V := \left(\frac{21}{Bridge\_Span}\right)^{\frac{1}{x}} \cdot \left(\frac{12 \cdot in}{d_{Effective}}\right)^{\frac{1}{x}} \cdot \left(\frac{5.125 \cdot in}{b_{Effective}}\right)^{\frac{1}{x}} \qquad C_V = 0.76 \qquad \text{(AASHTO 13.6.4.3)}$$

$C_L := 1.0$ Beam must be adequately braced with no danger of laterial buckling. (AASHTO 13.6.4.4)
Use the lesser of CV or CL in the equation given in AASHTO 13.6.4.1

$$F'_b := F_b \cdot C_{mb} \cdot C_D \cdot C_f \cdot C_V \qquad F'_b = 1308.99 \cdot \frac{lb}{in^2} \qquad \text{(AASHTO 13.6.4.1)}$$

$$F'_v := F_v \cdot C_{mv} \cdot C_D \qquad F'_v = 157.5 \cdot \frac{lb}{in^2} \qquad \text{(AASHTO 13.6.5.3)}$$

$$F'_{b\_Inv} := F'_b \qquad F'_{b\_Inv} = 1308.99 \cdot \frac{lb}{in^2} \qquad F'_{b\_Oper} := F'_b \cdot 1.33 \qquad F'_{b\_Oper} = 1740.96 \cdot \frac{lb}{in^2}$$

$$F'_{v\_Inv} := F'_v \qquad F'_{v\_Inv} = 157.5 \cdot \frac{lb}{in^2} \qquad F'_{v\_Oper} := F'_v \cdot 1.33 \qquad F'_{v\_Oper} = 209.48 \cdot \frac{lb}{in^2}$$

Calculation of Dead Load Moments and Shears

$$DL_{Deck} := S_{Beam} \cdot t_{Plank} \cdot Wt_{Wood} \qquad DL_{Deck} = 159.75 \cdot \frac{lb}{ft}$$

$$DL_{Beam} := b \cdot d \cdot Wt_{Wood} \qquad DL_{Beam} = 150.15 \cdot \frac{lb}{ft}$$

$$DL_{Running\_Surface} := t_{Running\_deck} \cdot S_{Beam} \cdot Wt_{Wood} \qquad DL_{Running\_Surface} = 94.67 \cdot \frac{lb}{ft}$$

$$DL_{Total} := DL_{Deck} + DL_{Beam} + DL_{Running\_Surface} \qquad DL_{Total} = 404.57 \cdot \frac{lb}{ft}$$

$$M_{DL} := \frac{DL_{Total} \cdot (Bridge\_Span \cdot ft)^2}{8} \qquad M_{DL} = 116.52 \cdot ft \cdot kips$$

Horizontal Shear

The location of the maximum vertical shear occuring at the lesser of 3d or L/4 per AASHTO 13.3.1

$$Dist := if\left(3 \cdot d < \frac{1}{4} \cdot Bridge\_Span \cdot ft, 3 \cdot d, \frac{1}{4} \cdot Bridge\_Span \cdot ft\right) \qquad Dist = 12 \cdot ft$$

$$R_{DL} := \frac{DL_{Total} \cdot (Bridge\_Span \cdot ft)}{2} \qquad R_{DL} = 9.71 \cdot kips$$

$$V_{DL} := R_{DL} - DL_{Total} \cdot Dist \qquad V_{DL} = 4.85 \cdot kips$$

Calculation of Live Load Moments and Shears

This worksheet is set up for calculating HS20 live load moments and shears for simple span bridges. The worksheet can also be set up for four other standard vehicle Truck-Types: 1 - HS20,2 - U54,3 - U80,4 - U102 & 5 - L90. (see distribution factors for live load below.) The live load shear has been computed for a distance 3 times the beam depth or the quarter point, which ever is less. The shear at this point has been approximated by using a shear envelope approach.

Truck-Type : = 1

Figure 2-Page 2 of 4 of Mathcad® 6+ Worksheet

$M_{HS20} := mvldStdMaxM(Bridge\_Span, Truck\_Type)\cdot ft\cdot kips$ $\quad M_{HS20} = 296.08 \cdot ft\cdot kips$

$R_{HS20} := mvldStdMaxV(Bridge\_Span, Truck\_Type)\cdot kips$ $\quad R_{HS20} = 29 \cdot kips$ At support

$x := if(Dist + 28\cdot ft < Bridge\_Span\cdot ft, 36\cdot kips, if(Dist + 14\cdot ft < Bridge\_Span\cdot ft, 32\cdot kips, 16\cdot kips))$ $\quad x = 36 \cdot kips$

$V_{HS20} := R_{HS20} - Dist\cdot\left(\frac{x}{Bridge\_Span\cdot ft}\right)$ $\quad V_{HS20} = 20 \cdot kips$

Impact Factor

AASHTO 3.8.1.2 - None required for timber members.

I :=0

Distribution of Live Load Moment

The following is the live load distribution factor for bridges designed for one traffic lane from AASHTO Table 3.23.1. Beam Spacing in feet.

Kind Of Floor	Distribution Factor
Timber planks on timber beams	Beam Spacing / 4.0
Nail laminated 4" thick on timber	Beam Spacing / 4.0
Nail laminated 6" thick or greater on timber	Beam Spacing / 4.0
Glued Laminated 4" thick on glulam stringers	Beam Spacing / 4.5
Glued Laminated 6" thick or greater on glulam stringers	Beam Spacing / 6.0

Note: if beam spacing is greater than 6 feet. Assume flooring between stringers acts as a simple beam.

$DF_{LL} := \frac{S_{Beam}}{6.0\cdot ft}$ $\quad DF_{LL} = 0.95$

$M_{LL} := M_{HS20}\cdot(1 + I)\cdot DF_{LL}$ $\quad M_{LL} = 280.29 \cdot ft\cdot kips$

Load Rating - Moment

$M_{R\_inv} := F'_b\cdot S_x$ $\quad M_{R\_inv} = 399.97 \cdot ft\cdot kips$

$M_{R\_oper} := F'_{b\_Oper}\cdot S_x$ $\quad M_{R\_oper} = 531.97 \cdot ft\cdot kips$

$RF_{M\_inv} := \frac{M_{R\_inv} - M_{DL}}{M_{LL}}$ $\quad RF_{M\_inv} = 1.01$

$RF_{M\_oper} := \frac{M_{R\_oper} - M_{DL}}{M_{LL}}$ $\quad RF_{M\_oper} = 1.48$

$HS20\_Inv\_Rating\_M := RF_{M\_inv}\cdot 36\cdot ton$ $\quad HS20\_Inv\_Rating\_M = 36.41 \cdot ton$

$HS20\_Oper\_Rating\_M := RF_{M\_oper}\cdot 36\cdot ton$ $\quad HS20\_Oper\_Rating\_M = 53.36 \cdot ton$

Distribution of Live Load Vertical Shear

The following is the live load distribution factor from AASHTO 13.6.5. The distribution shall be determined by the following equation:

$$V_{LL} = 0.50 * [(0.6 * V_{LU}) + V_{LD}]$$

Figure 3-Page 3 of 4 of Mathcad® 6+ Worksheet

$V_{LU} := V_{HS20}$

$V_{LD} := DF_{LL} \cdot V_{HS20}$

$V_{LL} := 0.5 \cdot \left[\left(0.6 \cdot V_{LU} \right) + V_{LD} \right]$

$V_{LL} = 15.47 \cdot kips$

Load Rating - Shear

$V_{R\_oper} := \frac{2}{3} \cdot A_V \cdot F'_{v\_Oper}$

$V_{R\_oper} = 60.39 \cdot kips$

$RF_{V\_inv} := \frac{V_{R\_inv} - V_{DL}}{V_{LL}}$

$RF_{V\_inv} = 2.62$

$RF_{V\_oper} := \frac{V_{R\_oper} - V_{DL}}{V_{LL}}$

$RF_{V\_oper} = 3.59$

$HS20\_Inv\_Rating\_V := RF_{V\_inv} \cdot 36 \cdot ton$

$HS20\_Inv\_Rating\_V = 94.39 \cdot ton$

$HS20\_Oper\_Rating\_V := RF_{V\_oper} \cdot 36 \cdot ton$

$HS20\_Oper\_Rating\_V = 129.26 \cdot ton$

Final Load Rating

This final step compares the capacity of the bridge in shear and bending. The result is the less of the two.

Inventory_Load_Capacity:= | HS20_Inv_Rating_V if HS20_Inv_Rating_V<HS20_Inv_Rating_M
HS20_Inv_Rating_M otherwise

Operating_Load_Capacity:= | HS20_Oper_Rating_V if HS20_0per_Rating_V<HS20_Oper_Rating_M
HS20_Oper_Rating_M otherwise

This **bridge has a HS20** Inventory_Load_Capacity = 36.41 •ton

This bridge has a HS20 Operating_Load_Capacity = 53.36 •ton

Figure 4-Page 4 of 4 of Mathcad ® 6+ Worksheet

Summary

The Mathcad® 6+ worksheet and QuickBASIC program have worked well for load rating this type of structure. Alterations to the Mathcad® 6+ worksheet may be made with ease for load rating other bridge types, but are not so easy for the basic program. Both load rating applications have their downside. The Mathcad 6+ worksheets are quite lengthy, but all equations used in load rating maybe viewed and checked. The basic program has a smaller output, but acts as a "black box". All equations are hidden and cannot be checked. The Mathcad 6+ worksheet maybe tailored to fit any specific structure and saved for future use. The basic program does not have this function at this time, but maybe modified in the future to allow for saving a file.

Load rating bridges using Mathcad® 6+ or the QuickBASIC program turned out to be a very economical and viable solution for this bridge type and with minor effort could be implemented for other types of bridges. In my opinion, the Mathcad® 6+ worksheet is the most versatile and viable application for load rating bridges.

Conversion Table

1 inch = 2.54 centimeters
1 foot = .3048 meters
1 pound = .454 kilograms
1psi = 6.895 kiloPascals
1 ton = 907.185 kilograms

* *

Glue-Laminated Bridge Rating

* *

Location:	Zarembo Island
Bridge :	McCormick Creek
Last Inspection :	7/15/95
Operator:	JSG
Date :	7/15/95

- -

Bridge Clear Span, Feet.	48
Bridge Width, Feet.	16
Number of Glulam Beams.	3
Location of Beam being analyzed.	Interior
Beam Height, Inches.	51
Assumed Height Reduction, Inches.	0
Beam Width, Inches.	8.5
Assumed Width Reduction, Inches.	0
Deck Thickness, Inches.	6.75
Running Surface Thickness, Inches.	4
Total Other Dead Load, lb/ft.	0
Wood Type & Grade.	Douglas Fir
Basic Allowable Bending Stresses, psi.	2400
Basic Allowable Shear Stress, psi.	200
Assumed Moisture Condition.	Wet
Load Duration Factor.	.9
Deck Type	Glulam Panels

- -

Without considering impact and load distribution factors:

Max.	Allowable	Inventory	Moment	=	400.0	ft-kips
Max.	Allowable	Operating	Moment	=	532.0	ft-kips
Max.	Allowable	Inventory	Shear	=	45.4	kips
Max.	Allowable	Operating	Shear	=	60.4	kips

Considering appropriate impact and load distribution factors:

HS20 (32.66 Metric Tons) Inventory Rating	=	36.4 Tons - controlled by moment
Operating Rating	=	53.4 Tons - controlled by moment

* *

Figure 5 - Basic Program Output

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