Michigan Department of Transportation

STRUCTURAL ANALYSIS DOCUMENTATION
Construction &Technology Division
Bridge Operations Section

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SUBJECT: GUSSET PLATE LFR ANALYSIS V2.2

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The analysis portion of the spreadsheet is protected. To unprotect, choose Tools -? Protection -> Unprotect Sheet. The password is “password”.

This documentation will describe the steps needed to complete the “Gusset Plate LFR Analysis V2.2.xls” spreadsheet, provide code references, identify cell locations and explain steps/formulas. This analysis is based upon FHWA Guidance Documents and AASHTO Standard Specifications for Highway Bridges (AASHTO STD)

If the gusset plate and splice plate are not similar on each side of the joint, multiple sheets may be used.

Evaluations are based upon three sections and all five members. Five members are not required in order to use this worksheet.

Unusual configurations such as a break in the alignment of the chord may require checking additional sections. This may be accomplished by using multiple spreadsheets and adjusting the Section input values.

This spreadsheet assumes that there are two gusset plates at the joint, one on each side of the main members.

This spreadsheet is designed to aid a qualified engineer in completing the analysis of a gusset plate. Sound engineering judgment and familiarity with the analysis of truss bridges and gusset plates are required to choose appropriate input values and to recognize situations that may deviate from the standard case on which this spreadsheet is based. The following documentation is meant to provide the engineer with information concerning the calculations in order for the engineer to determine if the spreadsheet is suitable for the plate in question, and to aid in modifications for unique circumstances.

Blue Font represents changes made in V1.1. Purple Font represents changes made in V2.0. Green Font represents changes made in V2.2.

Cell Color Coding:

Input
Header
Calculation
Intermediate Result
Final Result

INPUT

MEMBER ANGLES AND UNSUPPORTED EDGE DISTANCES

- Based on Figure 1, enter the angle that each member deviates from true vertical into cells C12 through C16.
    - Input a positive angle for members that are clockwise from vertical and a negative angle for members that are counter clockwise from vertical.
    - If analyzing a joint in the upper chord, rotate the joint 180 degrees so that the orientation matches that of Figure 1.
    - Should the joint not have all five members then enter 99 for all dimensions and 0.01 for all forces
    - This input will be used to determine forces in the cut sections.
- Based on Figure 1, enter the unsupported edge distance between each member into cells C18 through C21.
    - The length should be taken from the center to center of outermost connection holes.
    - This input will be used to determine the Combined Axial and Bending Rating Factor.

GUSSET AND SPLICE PLATE DIMENSIONS

- Enter the thickness of the gusset plate in cell C35. This is the minimum thickness. Variable thickness is not an option in the current version of the spreadsheet. This input will be used in calculating section properties and determining plate capacity.
- As shown in Figure 2, enter the height of the splice plate in cell C36. This input will be used in calculating section properties. If there is no splice plate, enter 0.
- Enter the length of the splice plate (in the direction of members A and E) in cell C37. This input will be used in calculating section properties. If there is no splice plate, enter 0.
- As shown in Figure 2, enter the thickness of the splice plate in cell C38. This input will be used in calculating section properties. If there is no splice plate, enter 0.
- As shown in Figure 2, enter the vertical offset between the gusset plate and the splice plate in cell C39. This input will be used in calculating section properties.
- As shown in Figure 2, enter the horizontal offset between the back of the gusset plate and the front of the splice plate in cell C40. This input will be used in calculating section properties.

MATERIAL PROPERTIES

- Enter the Ultimate Tensile Strength of the gusset plate in cell C46.

- Enter the Yield Strength of the gusset plate in cell C47.
- Enter the Poisson's Ratio of the gusset plate material in cell C48. A value of 0.3 is assumed for steel.
- Enter the Modulus of Elasticity of the gusset plate in cell C49. A value of 29000-ksi is assumed for steel.
- Enter the Effective Length Factor, K, based on Figure 3, in cell C50. Values of 1.0 for plates braced against sidesway and 2.0 for plates not braced against sidesway (top chords of pony trusses for example) are recommended for preliminary analysis.
- Enter the Shear Reduction Factor in cell C51.
  - $\Omega = 1.00$ for the case of uniform shear stress distribution where the gusset plates are of ample stiffness to prevent buckling and develop the plastic shear force of the plates, or
  - $\Omega = 0.74$ for the case of flexural shear stress distribution, and in the absence of a more rigorous analysis or criterion to assure and quantify the stiffness requirements to develop the plastic shear force of the plates.

UNFACTORED MEMBER FORCES DUE TO DEAD AND LIVE LOADS

- Enter Unfactored Dead Loads for Members A through E in cells E69 through E73. Enter the total load for the members, ***not*** the load for one gusset plate.
  - Tensile loads are positive. Compressive loads are negative.
- Enter Unfactored Live Loads plus Impact for Members.
  - Should the member experience stress reversal due to different loading configurations, the loads should be entered:
    - Enter maximum tensile loads (positive) in cells G69 through G73.
    - Enter maximum compressive loads (negative) in cells I69 through I73.
  - If the member does not experience stress reversal, enter the same loading in each column.
- Enter the Live Load factor in cell C76. This cell is used to increase Live Loads.
  - 2.17 is typical for Inventory Level.
  - 1.3 is typical for Operating Level.
- Choose the loading configuration in cell C77. This cell determines whether or not the factor entered in cell C78 should be used when combining loads.
  - "maximum" implies that the maximum value for each member was entered, although it is not likely that it is caused by the same truck position. It is assumed that initial calculations will use maximum values and concurrent forces will only be used if limit states are near or below one for maximum values.
  - "concurrent" implies that one member or limit state was maximized through the truck position and the forces for the other members were recorded. It is expected that different truck positions would increase loading in the other members. Multiple spreadsheets would need to be used in order to appropriately capture all limits if concurrent loading is applied.
- Enter the non-current reduction factor in cell C78. This value is only used if cell C77 is set to "maximum".
  - This factor reduces any live load that is opposite in sign to the limit being checked (for instance a negative value in a tensile check). Using maximum compressive

    forces of one member may be under-conservative when checking tensile capacity of a section.
  - A starting value of 0 would be conservative. This may be increased through engineering judgment but should not exceed 1.0.
    - A value of 0.9 may be appropriate, see discussion on Dead Load Factors below.
- Enter the minimum Dead Load Factor in cell C79 and the maximum Dead Load Factor in cell C80.
  - A value of 0.9 is recommended for the minimum Dead Load Factor.
    - Table 3.4.1-2 of AASHTO LRFD Bridge Design Specifications, 4th Ed with 2008 Interims, gives a dead load factor minimum of 0.9. This value is designed to reduce the effect of the dead load when adding dead load artificially through a load factor would increase the capacity and therefore make the analysis under-conservative.
  - A value of 1.3 is standard for the maximum Dead Load Factor in the Load Factor Rating Method.

BOLT/RIVET DESIGN STRENGTH

- Enter ϕF from either AASHTO STD 10.56 or Figure 4 in cell C99. This value is used in determining connector shear and resistance.
- Enter the nominal diameter of the bolts are rivets in cell C100.
- Enter the hole diameter in cell C101. Standard holes may be assumed to be 1/8-in greater than the bolt/rivet diameter per AASHTO STD 10.16.14.6.
- The area of one bolt/rivet is calculated in cell C102 according to the formula:

$$A_{bolt} = \frac{\pi * d_{bolt}}{4}$$

- **Note: Slip is not checked in this spreadsheet. The connections at the time of construction of most trusses were not considered slip-critical.

OPTIONAL CAPACITY REDUCTION

- While not mentioned in the body of the FHWA guidance, the example includes a 10% reduction in capacity. Cell C107 allows the engineer to determine the appropriate value.
  - "Since the failure of gusset plates in non-redundant structures may result in the collapse of the bridge, the capacity is therefore reduced by 10% to increase the margin of safety."

GUSSET CONNECTION DETAILS

- Enter the number of shear planes per bolt/rivet in cells E122 through E126. This input will be used in determining connection capacity.
  - Most connections only have one shear plane per bolt/rivet. If splice plates are present there may be two shear planes.
- Enter the number of bolts/rivets in each member component connected to a single gusset plate in cells G122 through G126. This input will be used in determining connection capacity and net section properties.
- Enter the bolt/rivet clear distance in cells I122 through I126. This input will be used in determining connection capacity and net section properties.

  - The bolt/rivet clear distance is the minimum of the clear distance between the holes or between the hole and the edge of the material in direction of the applied force.
- As shown in Figure 5, enter the number of rows of bolts/rivets per member component connected to a single gusset plate in cells C134 through C138.
  - If the bolt/rivet holes are staggered, enter the information as if they are not staggered. This will be conservative and may require modification of the spreadsheet if the checks dependent on this calculation control (Net Shear Resistance of Section, Tensile Resistance of Member)
- As shown in Figure 5, enter the shear resistance length per member component connected to a single gusset plate in cells C139 through C143. This input is used in developing section properties for Tensile Member Resistance.
  - This distance is from the center of the lead bolt/rivet to the edge of the plate along the outer line of bolts.
  - Should the length on each side of the plate vary, enter the average length.
- As shown in Figure 5, enter the tensile resistance length per member component connected to a single gusset plate in cells C144 through C148. This input is used in developing section properties for Tensile Member Resistance.
  - This is the center to center of the lead bolt/rivets
- As shown in Figures 5 and 6, enter the unbraced compression lengths, three for each member except member E, in cells C149 to C160.
  - This is a line drawn parallel to the member at each edge and the center of the Whitmore Width that ends when it intersects a line of bolts from another member.
  - According to the FHWA Guidance, to determine the Whitmore Width, the effective width is measured across the last row of fasteners in the connection under consideration. The effective width is bound on either side by the closer of the nearest adjacent plate edges or lines constructed starting from the external fasteners within the first row and extending from these fasteners at an angle of 30 degrees with respect to the line of action of the axial force. The Whitmore Width can extend into the influence of adjacent members. Figure 6 demonstrates this method.
  - Should the edges of the Whitmore Width (L_1 or L_3) intersect a line of bolts from another member, that individual length may be taken as 0.
  - Member E and Member A apply compression forces in the same area and so only Member A is required for this input.
  - This input will be used in calculating Member Compressive Capacity.
- As shown in Figure 6, enter the Whitmore Width for each member in cells C161 to C165.
  - According to the FHWA Guidance, to determine the Whitmore Width, the effective width is measured across the last row of fasteners in the connection under consideration. The effective width is bound on either side by the closer of the nearest adjacent plate edges or lines constructed starting from the external fasteners within the first row and extending from these fasteners at an angle of 30 degrees with respect to the line of action of the axial force. The Whitmore Width can extend into the influence of adjacent members. Figure 6 demonstrates this method.
  - This input will be used in calculating Member Compressive Capacity.

HORIZONTAL SECTION A-A

(Figure 7) These values are used to determine Section properties.

- Enter the width of the section into cell C175.

- Enter the distance from the edge containing member B to the vertical extension of the joint center in cell C176.
- Enter the vertical offset of the section from the joint center in cell C177.
- *Note* this section assumes that members A and E are straight. If the members have a break in alignment, additional sections may need to be checked to identify the controlling section.
- The section should be taken at the point of greatest eccentricity (maximizing the vertical offset in cell C176) without meeting with the first bolt/rivet holes of members B, C or D. The net section will still be calculated as if the section was taken at the first line of bolts/rivets. If the width of the gusset plate varies significantly at the line of bolts/rivets and the point of maximum eccentricity, and the net section check for the section controls, additional calculations may be required.

VERTICAL SECTION B-B
(Figure 8) These values are used to determine section properties.

- Enter the height of the section into cell C186.
- Enter the horizontal offset of the section from the joint center in cell C187.
- Enter the vertical offset of the section from the joint center in cell C188.
- Enter the number of bolts/rivets for member E that are included in Section B-B in cell C189. This will determine the amount of force from member E that is applied to Section B-B.

VERTICAL SECTION C-C
(Figure 9) These values are used to determine section properties.

- Enter the height of the section into cell C204.
- Enter the horizontal offset of the section from the joint center in cell C205.
- Enter the vertical offset of the section from the joint center in cell C206.
- Enter the number of bolts/rivets for member A that are included in Section C-C in cell C207. This will determine the amount of force from member A that is applied to Section C-C.

CALCULATIONS

UN-FACTORED HORIZONTAL AND VERTICAL COMPONENTS OF MEMBER FORCES (page 5)

- The calculations in this section determine the horizontal and vertical components of the member forces input in cells E69 through E73, G69 through G73, and I79 through I73 using the member angles input in cells C12 through C16. All formulas are shown for each component force.
- The forces from the members are divided in half in these calculations as there are assumed to be two gusset plates at each joint.
- The component forces are separated by member, direction (vertical or horizontal), and load case (dead, live load 1 and live load 2).
- These force components will be used in generating the forces and stressing in the section checks.

- The flexural rigidity is calculated in cell C267. This number is based upon material properties and the thickness of the plate.
    - It is used in the combined flexural and axial loading check.
    - It is assumed that the thickness of the plate is uniform.

A-A SECTION PROPERTIES

- The calculations in this section determine the section properties used in evaluating section A-A.
- All formulas are shown for each item.

UN-FACTORED FORCES ACTING ON SECTION A-A
(but accounting for concurrency)

- The calculations in this section sum the member forces from page 5 and calculate moments and stresses specific to Section A-A.
- The calculations for Dead Loads are shown exactly by the formula for each force/moment/stress.
- For combined axial and bending, three cases are checked
    - a – maximum positive axial force (Case 1) and maximum negative axial force (Case 2)
    - b – maximum negative moment
        - Not checked for concurrent loading as only case 1-a and 2-a are needed.
        - For “maximum loading”, the axial force (Case 1 or Case 2) will be included that is the same sign as the stress caused by the moment, which will vary depending upon the edge under review. This may be overly conservative depending upon the loading scenario.
    - c – maximum positive moment
        - Not checked for concurrent loading as only case 1-a and 2-a are needed.
        - For “maximum loading”, the axial force (Case 1 or Case 2) will be included that is the same sign as the stress caused by the moment, which will vary depending upon the edge under review. This may be overly conservative depending upon the loading scenario.
- Vertical Force (Rows 340 to 342)
    - DL is the sum of the member forces as given in the equation.
    - For concurrent loading selected in C77, the calculations for LL match the equations given.
    - For maximum loading selected in C77, the calculations for LL are modified as follows:
        - a - LL
            - Case 1: Finds maximum positive force.
                - If the individual member force is negative it is reduced by the factor entered in C78.
            - Case 2: Finds maximum negative force.
                - If the individual member force is positive it is reduced by the factor entered in C78.
        - b - LL
            - Sum of forces from all members, accounting for maximum loading.

        - If a positive axial force produces a negative moment, the maximum force is included. If a negative axial force produces a negative moment, the minimum force is included. If the axial force produces a positive moment it is reduced by the factor entered in C78.
      - c - LL
        - Sum of forces from all members, accounting for maximum loading.
        - If a positive axial force produces a positive moment, the maximum force is included. If a negative axial force produces a positive moment, the minimum force is included. If the axial force produces a negative moment it is reduced by the factor entered in C78.
- Moment for Member (Rows 345 to 357)
  - DL is the sum of the member forces as given in the equation.
  - For concurrent loading selected in C77, the calculations for LL match the equations given.
  - For maximum loading selected in C77, the calculations for LL are modified as follows:
    - a - LL
      - Case 1: If the axial force of the member is positive, the moment is included. If the axial force of the member is negative, the moment is reduced by the factor entered in C78.
      - Case 2: If the axial force of the member is negative, the moment is included. If the axial force of the member is positive, the moment is reduced by the factor entered in C78.
    - b - LL
      - Finds the maximum negative moment.
      - To find this, it identifies the sign of the moment arm.
      - If the moment arm is positive, it selects the minimum force (or maximum negative force) to create a negative moment.
      - If the moment arm is negative, it selects the maximum force (or maximum positive force) to create a negative moment.
    - c - LL
      - Finds the maximum positive moment.
      - To find this, it identifies the sign of the moment arm.
      - If the moment arm is negative, it selects the minimum force (or maximum negative force) to create a positive moment.
      - If the moment arm is positive, it selects the maximum force (or maximum positive force) to create a positive moment.
- Max Moments for Section (Rows 360 to 362)
  - DL
    - Sum of Member DL Moments from C345, C350 and C355
  - a
    - Sum of case 1a or 2a
  - b
    - For “concurrent” in cell C77, sums the Member LL Moments from cells C347, C352 and C357

        - For "maximum" in cell C77, finds maximum negative moment. If the individual member moment is positive it is reduced by the factor entered in C78.
    - c
        - For "concurrent" in cell C77, sums the Member LL Moments from cells H347, H352 and H357
        - For "maximum" in cell C77, finds maximum positive moment. If the individual member moment is negative it is reduced by the factor entered in C78.
- Shear Force (Rows 365 and 366)
    - Case 1: For "maximum" in cell C77, finds maximum negative shear. If the individual member shear is positive it is reduced by the factor entered in C78.
    - Case 2: For "maximum" in cell C77, finds maximum positive shear. If the individual member shear is negative it is reduced by the factor entered in C78.
- Axial Stress (Rows 369 to 371)
    - Not modified by cells C77 and C78, calculated as shown by formulas.
- Flexural Stress (Rows 374 to 379)
    - Not modified by cells C77 and C78, calculated as shown by formulas.

RESISTANCE OF SECTION BASED CHECKS: SHEAR FOR SECTION A-A

- Gross Shear Resistance (cell C391)
    - Gross Shear Resistance is taken from Eq 10-115 in the AASHTO STD with a reduction factor, Ω, as given in the FHWA guidance.
    - $\Omega = 1.00$ for the case of uniform shear stress distribution where the gusset plates are of ample stiffness to prevent buckling and develop the plastic shear force of the plates, or
    - $\Omega = 0.74$ for the case of flexural shear stress distribution, and in the absence of a more rigorous analysis or criterion to assure and quantify the stiffness requirements to develop the plastic shear force of the plates.
    - This spreadsheet uses uniform shear stress distribution, however it does not verify that the plate is of ample stiffness to prevent buckling and develop the plastic shear force of the plates. A value of 0.74 is recommended unless further analysis is performed to verify the use of 1.00.
- Gross Shear Rating Factor (cell C393)
    - Both LL inputs are checked.
        - If the DL is the same sign as the LL, a DL factor of C80 is used.
        - If the DL is the opposite sign as the LL, a DL factor of C79 is used.
    - The minimum rating factor is selected.
- Shear Fracture Resistance (cell C395, or Net Shear Resistance)
    - Shear Fracture Resistance uses the Net Section based on AASHTO STD 10.16.14 and the tensile steel strength rather than yield strength.
    - The 0.85 reduction factor is taken from AASHTO LRFD 6.5.4.2 which gives a reduction factor of 0.80 for fracture on the net section and 0.95 for yielding on gross section. As the LFD factor for yielding on gross section is 1.00, we divide the 0.80 factor by 0.95 in order to obtain similar levels of reliability as the Gross Shear Resistance. 0.80/0.95 = 0.842 which is rounded to 0.85 for simplicity.
- Net Shear Rating Factor (cell C397)

  - Both LL inputs are checked.
    - If the DL is the same sign as the LL, a DL factor of C80 is used.
    - If the DL is the opposite sign as the LL, a DL factor of C79 is used.
    - The minimum rating factor is selected.

RESISTANCE OF SECTION BASED CHECKS: COMBINED AXIAL AND BENDING FORCES/EDGE BUCKLING FOR SECTION A-A

- z, the ratio of bending to axial stresses is calculated in Rows 402 to 405.
  - The Dead Load Factor of C80 is included when the Dead Load is the same sign as the Live Load. The Dead Load Factor changes to C79 when the Dead Load is in the opposite sign as the Live Load.
  - For concurrent loading in cell C77, z is calculated without modifications.
  - For maximum loading in cell C77, z is modified as follows:
    - Case 1a is the maximum tensile (positive) axial stress with the moments/bending stresses associated with the loads that produce a positive axial stress. Compressive (negative) axial stresses and their corresponding moments/bending stresses are reduced by the factor given in C78.
    - Case 2a is the maximum compressive (negative) axial stress with the moments/bending stresses associated with the loads that produce a positive axial stress. Tensile (positive) axial stresses and their corresponding moments/bending stresses are reduced by the factor given in C78.
    - Case b is the maximum bending stress caused by a negative moment (as given in Figure 10) and the axial loads that cause these moments. This may cause tensile or compressive stresses depending on which edge (left or right) is being checked. Positive moment (as given in Figure 10) bending stresses and the axial loads that cause these moments are reduced by the factor given in C78.
    - Case c is the maximum bending stress caused by a positive moment (as given in Figure 10) and the axial loads that cause these moments. This may cause tensile or compressive stresses depending on which edge (left or right) is being checked. Negative moment (as given in Figure 10) bending stresses and the axial loads that cause these moments are reduced by the factor given in C78.
- The results of z have implications that are discussed below in order to clarify future steps taken in calculating the allowable edge buckling stress and corresponding rating factors. (Rows 408 to 411)
  - I - When $0 < z$, both the axial and bending total factored stresses have the same sign. The calculation of the critical buckling stress is straightforward as given in R-1519.
  - II - When $z = 0$
    - II.I - If the total factored bending stress is zero, z will be zero. The calculation of the total critical buckling stress is straightforward as given in R-1519.
    - II.II - If the total factored axial stress is zero, z cannot be calculated and a value of zero is given in the cell to avoid an error message. For the case of an axial stress as zero, the bending only equation from R-1519 should be used.

  - III - When $-1 < z < 0$, the axial and bending total factored stresses have different signs. In order for buckling to control, the axial force must be compressive as the axial stress does more work than the bending stress for this range of the ratio.
  - IV - When $z = -1$, the stress at the edge of the plate is zero, and so the total critical buckling stress is also calculated as zero. The critical bending buckling stress is the opposite sign of the critical axial buckling stress. For buckling of the plate to occur, the axial load would need to be in compression.
  - V - When $\frac{1}{\frac{1}{4}*\frac{b}{x_{NA}}-1} < z < -1$, the axial and bending total factored stresses have different signs. In this equation, "b" is the width of the plate from the edge to the point of fixity, and "x_{NA}" is the distance from the edge of the plate to the neutral axis. Dependent upon the section in question, "x_{NA}" may actually be "y_{NA}". In order for buckling to control, the axial force must be compressive as the axial stress does more work than the bending stress for this range of the ratio. However, in this range the total buckling stress would be calculated as tensile rather than compressive as the bending stress at the plate edge would be greater than the axial stress, although the axial stress is still doing more work on the plate.
  - VI - When $z = \frac{1}{\frac{1}{4}*\frac{b}{x_{NA}}-1}$, the axial and bending stresses cancel and no work is done on the plate. This causes a discontinuity in the calculation of the allowable edge buckling stress.
  - VII - When $z < \frac{1}{\frac{1}{4}*\frac{b}{x_{NA}}-1}$, the axial and bending total factored stresses have different signs. In order for buckling to control, the bending force must be compressive as the bending stress does more work than the axial stress at this ratio. In this case, the critical axial buckling stress may show a sign indicating tension, while the critical bending and the total critical buckling stresses would indicate compression.
- The allowable stress (edge buckling stress if live load causes compression or yielding stress if live load causes tension) is calculated in Rows 414 to 417. This stress is a conservative estimate of the edge stress that would cause buckling (or yielding) under the combination of loads specified. It is dependent upon the thickness of the plate, the flexural rigidity of the plate calculated in cell C267, the unsupported edge input in cells C18 through C21, and the width of the plate.
  - This value is considered to be conservative. If this limit state controls, it is recommended that further analysis such as Finite Element Analysis be performed.
  - See MDOT Research Report R-1519 for further information.
  - If the total live load (axial and bending) is in tension and the z case is I, II.I, II.II, VI, or VII then the capacity is taken as the yield stress.
  - If the axial live load is in tension and the z case is III, IV or V then the capacity is taken as the yield stress.

  - If the total live load is in compression, the capacity is reduced by a factor of 0.85 to account for out of plane bending, initial out-of-straightness, and other deviations from ideal which may reduce capacity. See AASHTO STD Eq 10-150 for similar reduction factor for columns in compression. Additionally, the maximum compressive stress is reduced to 0.85*Fy and multiplied by -1 to return a negative value.
  - The calculation for allowable buckling stress is dependent upon the category that the ratio “z” is in.
    - Cases I and II.I – calculation is per combined bending and axial stress equation from R-1519
    - Case II.II – calculation is per bending stress equation from R-1519
    - Case III – calculate the allowable axial compressive stress by removing the (1+z) term from the combined bending and axial stress equation from R-1519. The Rating Factor equation should be modified to only check for axial loads for this case.
      - If the axial live load force is tensile, a value of yield stress divided by -0.85 is returned so that the final answer is in tensile yield stress.
    - Case IV – the stress at the edge of the plate is zero. Calculate the allowable stress similar to Case III. The Rating Factor equation should be modified to only check for axial loads for this case.
      - If the axial live load force is tensile, a value of yield stress divided by -0.85 is returned so that the final answer is in tensile yield stress.
    - Case V – The total factored stress at the edge of the plate is tensile. It is not anticipated that this case would control, but it is included for completeness. Calculate the allowable stress similar to Case III. The Rating Factor equation should be modified to only check for axial loads for this case.
      - If the axial live load force is tensile, a value of yield stress divided by -0.85 is returned so that the final answer is in tensile yield stress.
    - Case VI – No work is done on the plate. The allowable stress is set to the yield stress.
    - Case VII – The calculation is per combined bending and axial stress equation from R-1519.
    - If the total live load is in compression but the bending live load at the edge is in tension, the allowable stress calculated is the critical axial stress taking the bending stress into account.
    - If the total live load is in compression but the axial live load is in tension, the allowable stress calculated is the critical bending stress assuming the axial force is zero. This may be conservative, but it accounts for cases where the denominator may become zero due to a negative z value.
- Combined Axial and Bending Forces Rating Factor (cells C414 to 421)
  - Only case a is checked for concurrent loading.
  - For Cases III, IV and V only the axial force is used as the bending force was used to calculate the capacity.
  - If the DL is the opposite sign as the live load, the reduced factor given in C79. If the DL is the same sign as the live load, the factor given in C80 is used.
  - The minimum rating factor is selected.

CALCULATIONS FOR SECTIONS B-B AND C-C

Calculations for Sections B-B and C-C are similar to those described above for Section A-A.

- For sections B-B and C-C, the member forces in A and E are reduced based on the percentage of connectors included in the Section.
- The splice plate (if present) is included in the calculations for Sections B-B and C-C
- Only the top edge is checked for combined axial and bending stresses as the bottom edge is attached to the member chords.

CONNECTION ANALYSIS OF MEMBER

- Length Reduction approximates the length of the dividing the total number of bolts/rivets (given in cells G122 to G126) by the number of rows (given in cells C134 through C138), subtracting 1 in order to arrive at the number of spaces and then multiplying by the clear distance given in cells I122 to I126.
- Shear Resistance of Connectors is calculated as shown according to AASHTO STD 10.56.1.3.
- Shear Resistance Rating Factor is calculated
  - The minimum rating factor of Case 1 and Case 2 is selected.
  - The capacity calculated in cell C663 is increased by a factor of 2 to account for two plates.
  - Case 1: Tension
    - If Case 1 LL is positive, the case is checked.
      - If the DL is positive, a DL factor of C80 is used.
      - If the DL is negative, a DL factor of C79 is used.
    - If the Case 1 LL is negative, a value of 99.99 is returned.
  - Case 2: Compression
    - If the Case 2 LL is negative, the case is checked.
      - If the DL is negative, a DL factor of C80 is used.
      - If the DL is positive, a DL factor of C79 is used.
    - If the Case 2 LL is positive, a value of 99.99 is returned.
- The Bearing Resistance of the Connectors is calculated as shown according to AASHTO STD 10.56.1.3.
- The Bearing Resistance Rating Factor is calculated
  - The minimum rating factor of Case 1 and Case 2 is selected.
  - The capacity calculated in cell C663 is increased by a factor of 2 to account for two plates.
  - Case 1: Tension
    - If Case 1 LL is positive, the case is checked.
      - If the DL is positive, a DL factor of C80 is used.
      - If the DL is negative, a DL factor of C79 is used.
    - If the Case 1 LL is negative, a value of 99.99 is returned.
  - Case 2: Compression
    - If the Case 2 LL is negative, the case is checked.
      - If the DL is negative, a DL factor of C80 is used.
      - If the DL is positive, a DL factor of C79 is used.
    - If the Case 2 LL is positive, a value of 99.99 is returned.

TENSILE ANALYSIS OF MEMBER

- The net-cross-sectional area is calculated as shown according to AASHTO STD 10.16.14
- β is calculated as 0 if the hole size exceeds 1.25-in or the steel is 100ksi and 0.15 for all other cases, as given in AASHTO STD 10.18.2.2.4.
- The effective area is calculated according to AASHTO STD 10-4g.
- The Tensile Capacity Rating Factor is calculated
    - If both Case 1 and Case 2 LL are less than 0 (compression), a rating factor of 99.99 is returned.
    - If the DL is positive, a DL factor of C80 is used.
    - If the DL is negative, a DL factor of C79 is used.
    - The maximum of Case 1 and Case 2 LL is used as only tensile forces are required.
    - The capacity calculated in cell C681 is increased by a factor of 2 to account for two plates.
- Similarly, the section properties for combined shear and tension were calculated.
    - The splice plate was included in section properties for tension but not shear
    - Only one shear-resistance line was accounted for in Members A and E as the other line is at the edge of the plate. Members B, C, and D have two shear-resistance lines.
    - In calculating the net area for shear resistance, the calculated number of bolt/rivet holes is subtracted by 0.5 bolt holes as the input for shear resistance length is from the center of the lead bolt/rivet to the edge of the plate.
    - In calculating the net area for tensile resistance, the number of bolt/rivet holes is subtracted by 1 bolt hole as the input for tensile resistance length is from center to center of the lead bolts/rivets.
- The Block Shear Rupture Resistance is calculated as shown.
    - The 0.85 reduction factor is taken from AASHTO LRFD 6.5.4.2 which gives a reduction factor of 0.80 for fracture on the net section and 0.95 for yielding on gross section. As the LFD factor for yielding on gross section is 1.00, we divide the 0.80 factor by 0.95 in order to obtain similar levels of reliability as the Gross Shear Resistance. 0.80/0.95 = 0.842 which is rounded to 0.85 for simplicity.
- The Block Shear Rupture Rating Factor is calculated
    - If both Case 1 and Case 2 LL are less than 0 (compression), a rating factor of 99.99 is returned.
    - If the DL is positive, a DL factor of C80 is used.
    - If the DL is negative, a DL factor of C79 is used.
    - The maximum of Case 1 and Case 2 LL is used as only tensile forces are required.
    - The capacity calculated in cell C681 is increased by a factor of 2 to account for two plates.

COMPRESSIVE ANALYSIS OF MEMBER

- The required section properties are calculated as shown.
- The Buckling Stress is calculated as given in AASHTO STD 10.54.1.1, Eq 10-151.
- The Compressive Capacity is calculated according to AASHTO STD 10.54.1.1, Eq. 10-150.
- The Compression Rating Factor is calculated
    - If both Case 1 and Case 2 LL are greater than 0 (tension), a rating factor of 99.99 is returned.

  - If the DL is negative, a DL factor of C80 is used.
  - If the DL is positive, a DL factor of C79 is used.
  - The minimum of Case 1 and Case 2 LL is used as only compressive forces are required.
  - The capacity calculated in cell C681 is increased by a factor of 2 to account for two plates.

Additional Changes Version 1.1

- Corrected cell reference for Section C-C
- Case 1 and 2 automatically selects the appropriate case instead of assuming which of the loads input should be used.
- Removed concurrency calculations for intermediate case b and c calculations.
- Separated value of z into 7 cases with slight modifications for how each case calculates allowable stress and Rating Factor.
- Change "b" for buckling stress calculations
  - For right side of section AA it is now $L_{AA} – X_{AA}$
  - For top of section BB and CC it is now
- Change "y_{NA}" for buckling stress calculations for sections BB and CC since with the possible presence of a splice plate the neutral axis may not be in the middle of the section.
  - This change is not needed for section AA as the neutral axis is in the middle of the plate.
- Do not take absolute value of critical buckling stress.
- Maximum buckling stress taken as 0.85*fy, similar to 10-150 of AASHTO STD Specs
- Corrected cell reference for:
  - RF v conn D and E
  - RF ten + shear member E

Additional Changes Version 2.0

- Added Capacity reduction to all capacities by multiplying by (1-C107). Setting C107 to 0 will return the full capacity.
- Corrected cell references in H402, C416, C417, H416 and H417.

Change Version 2.1

- Corrected formula in cell C797

Change Version 2.2

- Corrected cell references in cells C574, H574, C741 and H741

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