CSiBridge®

Bridge Rating

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Chapter 1 Introduction

CSiBridge is the ultimate integrated tool for modeling, analysis, and design of bridge structures. The ease with which all of these tasks can be accomplished makes CSiBridge the most versatile and productive bridge design package in the industry. CSiBridge offers an easy-to-use tool for load rating. The algorithms used in the rating requests comply with requirements of the *AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges October 2003 with 2005 Interim Revisions* through to *The Manual for Bridge Evaluation Second Edition 2010 with 2011, 2013, 2014, and 2015 Interims.* The interim revisions do not contain any changes that affect the program. This manual describes the algorithms applied to concrete box, multicell, precast I or U girders, and steel I-section deck superstructure bridge models.

In the case of concrete box bridges, CSiBridge applies an algorithm that idealizes the superstructure as a torsionally stiff single-spine beam, as defined in AASHTO LRFD Section 4.6.1.1.

In the case of a multicell concrete box bridge, CSiBridge analyzes the superstructure on a girder-by-girder (web-by-web) basis while ignoring the effects of torsion. The user has the option to use the individual girder demands directly from the CSiBridge model (available only for Area and Solid models) or use Live Load Distribution (LLD) factors. CSiBridge gives the user a choice of methods to address distribution of live load to individual girders.

In the case of precast I or U girder bridges, CSiBridge analyzes the superstructure on a girder-by-girder (beam-by-beam) basis while ignoring the effects of torsion. The user has the option to use the individual girder demands directly from the CSiBridge model (available only for Area and Solid models) or use Live Load Distribution (LLD) factors. CSiBridge gives the user a choice of methods to address distribution of live load to individual girders.

The evaluation and application of LLD factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

The CSIBridge program allows to select the AASHTO LRFD edition and applicable interim that is used for calculation of resistance of the superstructure.

1.1 Organization

This chapter identifies the applicable code and describes additional sources of information about CSiBridge's many features and advantages. Chapter 2 describes the algorithms for concrete box deck superstructures. Chapter 3 describes the algorithms for multicell concrete box deck superstructures. Chapter 4 describes the algorithms when the deck superstructure is comprised of precast I or U girders with composite slab. Chapter 5 describes the algorithms when the deck superstructure is comprised of a steel I-section with concrete slab.

1.2 Recommended Reading

It is strongly recommended that you read this manual and review any applicable "Watch & Learn" Series™ tutorials, which are found on our web site, http://www.csiamerica.com, before attempting to determine the bridge rating for a concrete box girder or precast concrete bridge using CSiBridge. Additional information can be found in the on-line Help facility available from within the software's main menu.

Also, other bridge related manuals include the following:

- *Defining the Work Flow* - Provides an overview of the work flow when using CSiBridge. That manual includes a description of the ***Bridge Wizard,*** a step-wise guide through the entire model creation, analysis, and design process, and explains the various tabs, panels, and commands of the user interface that can be used independently of or in concert with the ***Bridge Wizard***.

- *Introduction to CSiBridge* – Introduces CSiBridge design when modeling concrete box girder bridges and precast concrete girder bridges. The basic steps involved in creating a bridge model are described. Then an explanation of how loads are applied is provided, including the importance of lanes, vehicle definitions, vehicle classes, and load cases. The *Introduction* concludes with an overview of the analysis and display of design output.

- *Superstructure Design* – Describes using CSiBridge to complete bridge design in accordance with the AASHTO STD and AASHTO LRFD codes. Loading and load combinations and well as Live Load Distribution Factors are described. The manual explains how to define and run a design request and provides the algorithms used by CSiBridge in completing bridge design of various superstructure section types. The manual concludes with a description of design output, which can be presented graphically as plots, in data tables, and in reports generated using the Advanced Report Writer feature.

- *Seismic Analysis and Design* – Describes the eight simple steps needed to complete response spectrum and pushover analyses, determine the demand and capacity displacements, and report the demand/capacity ratios for an Earthquake Resisting System (ERS).

Chapter 2 Concrete Box Girder Bridges

This chapter describes the algorithm CSiBridge applies when load rating concrete box deck superstructures.

This algorithm idealizes the superstructure as a torsionally stiff single-spine beam, as defined in AASHTO LRFD Section 4.6.1.1. For load rating of multicell concrete boxes using live load distribution factors, see Chapter 3.

2.1 Load Rating - Flexure

2.1.1 Rating Factor

$$RF = \frac{\varphi M_n - \gamma_{DC} M_{DC} - \gamma_{DW} M_{DW} - \gamma_P M_P}{\gamma_L M_{LL+IM}}$$

AASHTO MBE eq. 6-1

RF = Rating factor calculated by CSiBridge

M_n = Nominal moment resistance calculated by CSiBridge

The following values are specified by the user in the Rating Request:

φ = Resistance factor for flexure; Default Value = 1.0, Typical value(s): 1.0. The φ factor is specified in the Rating Parameters form.

$\gamma_{DC}M_{DC}$ = Factored moment demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.

$\gamma_{DW}M_{DW}$ = Factored moment demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.

$\gamma_P M_P$ = Factored moment demand due to permanent loads other than dead loads. The γ_P factor shall be included in the combo specified in the P Combo demand set.

$\gamma_L M_{LL+IM}$ = Factored moment demand due to live load. The γ_L factor shall be included in the combo specified in the LL+IM Combo demand set.

2.1.2 Flexural Resistance

The flexural resistance is determined in accordance with selected AASHTO LRFD edition and applicable interim that were specified in the Bridge Rating Preferences form. Detailed description of resistance calculation is presented in the Bridge Superstructure Design manuals. The resistance is evaluated only for bending about horizontal axis 3. Separate resistance is calculated for positive and negative moment.

The moment resistance is based on bonded tendons and longitudinal mild steel reinforcement defined in the Bridge Object. It is assumed that all defined tendons in a section, stressed or not, have f_{pe} (effective stress after loses) larger than 0.5 f_{pu} (specified tensile strength). If a certain tendon should not be considered for the flexural resistance calculation, its area must be set to zero.

Only reinforcement in the tensile zone of the section is assumed to contribute to the moment resistance of the section; reinforcement in the compression zone is ignored.

2.1.3 Rating Factor Algorithm

In case any of the user-defined combos for demands sets $\gamma_{DC}M_{DC}$, $\gamma_{DW}M_{DW}$, or $\gamma_{p}M_{p}$ contain multiple StepTypes, the M3 demands from Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting the maximum absolute from the two StepType values while preserving the sign.

The rating factor is calculated for each StepType present in the $\gamma_{L}M_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

For each StepType, one of the section flexural capacities (positive or negative), to be used in the rating factor equation, is selected to match the sign of the $\gamma_{L}M_{LL+IM}$ moment. Then the sign of the sum of the moments $\gamma_{DC}M_{DC} + \gamma_{DW}M_{DW} + \gamma_{p}M_{p}$ is determined. If the sign of the sum matches the sign of the $\gamma_{L}M_{LL+IM}$, the moment resistance is reduced by the sum; if the sign of the sum is opposite, the moment resistance is increased by the sum.

2.2 Load Rating – Min Rebar for Flexure

In this rating request, CSiBridge verifies if the minimum reinforcement requirement is satisfied in accordance with AASHTO LRFD Section 5.7.3.3.2. The code states that the calculated flexural resistance M_r, based on the provided PT and longitudinal rebar, must satisfy the following requirement:

$$M_r > \min(1.2M_{cr},\ 1.33M_u)$$

where $M_{cr} = S_{c'}\,(f_r + f_{cpe}) \geq S_c f_r$ (calculated by CSiBridge)

S_c = section modulus for the extreme fiber of the section where tensile stress is caused by externally applied loads. The value is calculated by CSiBridge and reported in the output table.

f_{cpe} = compressive stress in concrete due to effective prestress force only (after allowance for all prestress losses) at the extreme fiber of the section where tensile stress is caused by externally applied loads. The user specifies the name of the combo for the f_{cpe} demand set in the definition of the Bridge Rating Request.

f_r = modulus of rupture. The user specifies this value in the Rating Parameters.

M_u = factored moment required by the applicable strength load combinations specified in AASHTO LRFD Table 3.4.1-1. The user specifies the name of the combo for the M_u demand set in the definition of the Bridge Rating Request.

2.2.1 Min Rebar for Flexure Algorithm

At each section, the resistances for both positive and negative moments are determined using the procedure outlined in Section 2.1.2. The f_{cpe} stresses at the top and bottom of the extreme fiber are read, and M_{cr} values for both positive and negative moments are evaluated.

For each StepType present in the M_u combo, the sign and magnitude of the M3 moment is read. If the M_u sign is negative, the minimum rebar equation is checked for negative flexural resistance, and if the M_u sign is positive, the minimum rebar equation is checked for positive flexural resistance. If both StepTypes present in the M_u combo have the same sign, the minimum rebar for the opposite sign moment is not checked and the note “Not applicable” is reported in the output table.

Chapter 3 Multicell Concrete Box Girder Bridges

This chapter describes the algorithm CSiBridge applies when load rating multicell concrete box deck.

This algorithm analyzes the superstructure on a girder-by-girder (web-by-web) basis while ignoring the effects of torsion. For load rating of concrete box bridges where the superstructure is idealized as a torsionally stiff, single-spine beam as defined in AASHTO LRFD Section 4.6.1.1, see Chapter 2.

The user has the option to use the individual girder demands directly from the CSiBridge model (available only for Area and Solid models) or use Live Load Distribution (LLD) factors. CSiBridge gives the user a choice of methods to address distribution of live load to individual girders. The evaluation and application of LLD factors is described in detail in Chapter 3 of the Bridge Superstructure Design manual.

It is important to note that to obtain relevant results, the definition of a Moving Load case must be adjusted depending on which method is selected. Refer to Chapter 3, Section 3.1 of the Bridge Superstructure Design manual.

Legend:
Girder = the web + the tributary area of the top and bottom slab
Section Cut = all girders present in the cross-section at the cut location

3.1 Load Rating – Flexure

3.1.1 Rating Factor

$$RF = \frac{\varphi M_n - \gamma_{DC} M_{DC} - \gamma_{DW} M_{DW} - \gamma_P M_P}{\gamma_L M_{LL+IM}}$$

AASHTO MBE *6A-4.2.1*

RF = Rating factor calculated by CSiBridge

M_n = Nominal moment resistance calculated by CSiBridge

The following values are specified by the user in the Rating Request:

φ = Resistance factor for flexure; Default Value = 1.0, Typical value(s): 1.0. The φ factor is specified in the Rating Parameters form.

$\gamma_{DC} M_{DC}$ = Factored moment demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.

$\gamma_{DW} M_{DW}$ = Factored moment demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.

$\gamma_P M_P$ = Factored moment demand due to permanent loads other than dead loads. The γ_P factor shall be included in the combo specified in the P Combo demand set.

$\gamma_L M_{LL+IM}$ = Factored moment demand due to live load. The γ_L factor shall be included in the combo specified in the LL+IM Combo demand set.

3.1.2 Flexural Resistance

The flexural resistance is determined in accordance with selected AASHTO LRFD edition and applicable interim that were specified in the Bridge Rating Preferences form. Detailed description of resistance calculation is presented in the Bridge Superstructure Design manuals. The resistance is evaluated only for bending about horizontal axis 3. Separate resistance is calculated for positive and negative moment.

The moment resistance is based on bonded tendons and longitudinal mild steel reinforcement defined in the Bridge Object. It is assumed that all defined tendons in a section, stressed or not, have f_{pe} (effective stress after loses) larger than 0.5 f_{pu} (specified tensile strength). If a certain tendon should not be considered for the flexural resistance calculation, its area must be set to zero.

Only reinforcement in the tensile zone of the section is assumed to contribute to the moment resistance of the section; reinforcement in the compression zone is ignored.

3.1.3 Live Load Distribution Into Girders

The M3 demands on the section cut specified in the LL+IM demand set are distributed into individual girders in accordance with the Live Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

M3 demands on the section cut specified in the DC, DW and P Combo demand sets are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders – available for Area and Solid models only). In that case, forces from CSiBridge are read directly on a girder-by-girder basis.

3.1.4 Rating Factor Algorithm

In case any of the user defined combos for demands sets $\gamma_{DC}M_{DC}$, $\gamma_{DW}M_{DW}$, or $\gamma_p M_p$ contain multiple StepTypes, the M3 demands from Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting the maximum absolute from the two StepType values while preserving the sign.

The girder rating factor is calculated for each StepType present in the $\gamma_L M_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

For each StepType, one of the girder flexural capacities (positive or negative), to be used in the rating factor equation, is selected to match the sign of the $\gamma_L M_{LL+IM}$ moment. Then the sign of the sum of the moments $\gamma_{DC}M_{DC} + \gamma_{DW}M_{DW} + \gamma_p M_p$ is determined. If the sign of the sum matches the sign of the $\gamma_L M_{LL+IM}$, the moment resistance is reduced by the sum; if the sign of the sum is opposite, the moment resistance is increased by the sum.

3.2 Load Rating – Min Rebar for Flexure

In this rating request, CSiBridge verifies if minimum reinforcement requirement is satisfied in accordance with AASHTO LRFD 5.7.3.3.2. The code states that the calculated flexural resistance M_r, based on the provided PT and longitudinal rebar, must satisfy the following requirement:

$$M_r > \min(1.2M_{cr}, 1.33M_u)$$

where $M_{cr} = S_{c'}(f_r + f_{cpe}) \geq S_c f_r$ (calculated by CSiBridge)

S_c = section modulus for the extreme fiber of the section where tensile stress is caused by externally applied loads. The value is calculated by CSiBridge and reported in the output table.

f_{cpe} = compressive stress in concrete due to effective prestress force only (after allowance for all prestress losses) at the extreme fiber of the section where tensile stress is caused by externally applied loads. The user specifies the name of the combo for the f_{cpe} demand set in the definition of the Bridge Rating Request.

f_r = modulus of rupture. The user specifies this value in the Rating Parameters.

M_u = factored moment required by the applicable strength load combinations specified in AASHTO LRFD Table 3.4.1-1. The user specifies the name of the combo for the M_u demand set in the definition of the Bridge Rating Request.

3.2.1 Live Load Distribution into Girders

The M3 demands on the section cut specified in the M_u demand set are distributed into individual girders in accordance with the Live Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

M3 demands on section cut specified in f_{cpe} combo demand set are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders -- available for Area and Solid models only). In that case, forces from CSiBridge are not read on a section-cut basis but directly on a girder-by-girder basis.

3.2.2 Min Rebar for Flexure Algorithm

At each girder, the resistances for both positive and negative moments are determined using the procedure outlined in Section

3.1.2. The f_{cpe} stresses at the top and bottom of the extreme fiber are read, and M_{cr} values for both positive and negative moments are evaluated.

For each StepType present in M_u combo, the sign and magnitude of the M3 moment is read. If the M_u sign is negative, the minimum rebar equation is checked for negative flexural resistance and if the M_u sign is positive, the minimum rebar equation is checked for positive flexural resistance. If both StepTypes present in the M_u combo have the same sign, the minimum rebar for the opposite sign moment is not checked and the note "Not applicable" is reported in the output table.

3.3 Load Rating - Shear

3.3.1 Rating Factor

$$RF = \frac{\varphi V_n - \gamma_{DC} V_{DC} - \gamma_{DW} V_{DW} - \gamma_p V_p}{\gamma_L V_{LL+IM}}$$

AASHTO MBE eq. 6A-4.2.1

RF = Rating factor calculated by CSiBridge

V_n = Nominal shear resistance calculated by CSiBridge

The user specifies values for the following in the Rating Request:

φ = Resistance factor for shear; Default Value = 0.9, Typical value(s): 0.9 for normal weight concrete, 0.7 for light-weight concrete. The φ factor is specified in the Rating Parameters form.

$\gamma_{DC} V_{DC}$ = Factored shear demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.

$\gamma_{DW}V_{DW}$ = Factored shear demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.

$\gamma_{P}V_{P}$ = Factored shear demand due to permanent loads other than dead loads. The γ_{P} factor shall be included in the combo specified in the P Combo demand set.

$\gamma_{L}V_{LL+IM}$ = Factored shear demands due to live load. The γ_{L} factor shall be included in the combo specified in the LL+IM Combo demand set.

3.3.2 Live Load Distribution into Girders

The V2 demands on the section cut specified in the LL+IM and M_u demand sets are distributed into individual girders in accordance with the Live Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

V2 demands on the section cut specified in the DC, DW and P Combo demand sets are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders – available for Area and Solid models only). In that case, forces from CSiBridge are read directly on a girder-by-girder basis.

3.3.3 Shear Resistance

The shear resistance is determined in accordance with selected AASHTO LRFD edition and applicable interim that were specified in the Bridge Rating Preferences form. Detailed description of resistance calculation is also presented in the Bridge Superstructure Design manuals.

The shear resistance is determined in accordance with paragraph 5.8.3.4.2 (derived from the Modified Compression Field Theory). The procedure assumes that the concrete shear stresses are distributed uniformly over an area b_v wide and d_v deep, that the direction of principal compressive stresses (defined by angle θ and shown as D) remains constant over d_v, and that the shear strength of the section can be determined by considering the biaxial stress conditions at just one location in the web. The user should select for design only those sections that comply with these assumptions by defining appropriate station ranges in the design request (see Chapter 4 of the *Bridge Superstructure Design* manual).

The effective web width is taken as the minimum web width, measured parallel to the neutral axis, between the resultants of the tensile and compressive forces as a result of flexure. In determining the effective web width at a particular level, one-quarter of the diameter of the grouted ducts at that level is subtracted from the web width.

All defined tendons in a section, stressed or not, are assumed to be grouted. Each tendon at a section is checked for presence in the web and the minimum controlling effective web thicknesses are evaluated.

The tendon duct is considered as having effect on the web effective thickness even if only part of the duct is within the web boundaries. In such cases, the entire one-quarter of the tendon duct diameter is subtracted from the element thickness

If several tendon ducts overlap in one web (when projected on vertical axis), the diameters of ducts are added for the sake of evaluation of the effective thickness. The effective web thickness is calculated at the top and bottom of each duct.

Shear design is completed on a per-web (girder) basis; torsion is ignored.

Transverse reinforcement specified in the Bridge Object is used to verify if minimum shear reinforcement is provided. It is also used to calculate the V_s shear resistance component. The density (area per unit length) of provided transverse reinforcement in a given girder is averaged based on values specified in the Bridge Object over a distance 0.5 $d_v \cot\theta$ measured down-station and up-station from a given section cut.

3.3.4 Shear Resistance Parameters

The following parameters are considered during shear design:

- M_u Combo Demand Set – the forces in the specified combo are used in the Modified Compression Field Theory (MCFT) equations to determine shear resistance of the girder.
- *PhiC* – Resistance Factor; Default Value = 0.9, Typical value(s): 0.7 to 0.9. The nominal shear resistance of normal weight concrete sections is multiplied by the resistance factor to obtain factored resistance.
- *PhiC* (*Lightweight*) – Resistance Factor for light-weight concrete; Default Value = 0.7, Typical value(s): 0.7 to 0.9. The nominal shear resistance of light-weight concrete sections is multiplied by the resistance factor to obtain factored resistance.
- *Check Sub Type* – Typical value: MCFT. Specifies which method for shear design will be used: either MCFT in accordance with 5.8.3.4.2; or the V_{ci}/V_{cw} method in accordance with 5.8.3.4.3 Currently only the MCFT option is available.

- *Negative limit on strain in nonprestressed longitudinal reinforcement* in accordance with section 5.8.3.4.2; Default Value = $-0.4\text{x}10^{-3}$, Typical value(s): 0 to $-0.4\text{x}10^{-3}$
- *Positive limit on strain in nonprestressed longitudinal reinforcement* in accordance with section 5.8.3.4.2; Default Value = $6.0\text{x}10^{-3}$, Typical value(s): $6.0\text{x}10^{-3}$
- *PhiC for* N_u – Resistance Factor used in equation 5.8.3.5-1; Default Value = 1.0, Typical value(s): 0.75 to 1.0
- *Phif for* M_u – Resistance Factor used in equation 5.8.3.5-1; Default Value = 0.9, Typical value(s): 0.9 to 1.0.
- *sx* = Maximum distance between layers of longitudinal crack control reinforcement in accordance with AASHTO LRFD 5.8.3.4.2-5. This parameter is used only when a girder does not contain the code-specified minimum amount of shear reinforcement.
- *ag* = Maximum aggregate size, Eq 5.8.3.4.2. This parameter is used only when a girder does not contain the code-specified minimum amount of shear reinforcement.

3.3.5 Shear Resistance Variables

A_c = Area of concrete on the flexural tension side of the member

A_{ps} = Area of prestressing steel on the flexural tension side of the member

A_{vl} = Area of nonprestressed steel on the flexural tension side of the member at the section under consideration

$A_{v\text{prov}}$ = Area of transverse shear reinforcement per unit length as specified in the Bridge Object. The transverse reinforcement density is averaged over a distance 0.5 $\cot\theta$ measured up-station and down-station from the current section cut.

$A_{VS\,\mathrm{min}}$ = Minimum area of transverse shear reinforcement per unit length in accordance with eq. 5.8.2.5

E_c = Young's modulus of concrete

E_p = Prestressing steel Young's modulus

E_s = Reinforcement Young's modulus

M_u = Factored moment at the section

N_u = Applied factored axial force, taken as positive if tensile

$V_{2\mathrm{c}}$ = Shear in section cut excluding force in tendons

$V_{2\mathrm{Tot}}$ = Shear in section cut including force in tendons

V_p = Component in the direction of the applied shear of the effective prestressing force; if V_p has the same sign as V_u, then the component is resisting the applied shear

V_u = Factored shear demand per girder excluding force in tendons

a = Depth of equivalent stress block in accordance with 5.7.3.2.2. Varies for positive and negative moment.

b = Minimum web width

b_v = Effective web width adjusted for the presence of prestressing ducts in accordance with section 5.8.2.9

d_{girder} = Depth of girder

d_p = Distance from compression face to center of gravity of tendons in the tensile zone

d_s = Distance from compression face to center of gravity of longitudinal reinforcement in the tensile zone

d_v = Effective shear depth in accordance with 5.8.2.9

f_{pu} = Specified tensile strength of prestressing steel

$\varepsilon_{\text{sLimitPos}}, \varepsilon_{\text{sLimitNeg}}$ = Max and min value of strain in nonprestressed longitudinal tension reinforcement as specified in the Design Request

ε_s = Strain in nonprestressed longitudinal tension reinforcement – eq. 5.8.3.4.2-4

ϕ_F = Resistance factor for moment

ϕ_P = Resistance factor for axial load

ϕ_V = Resistance factor for shear

λ = Multiplier of $\sqrt{f_c'}$ for light-weight concrete in accordance with 5.8.2.2

3.3.6 Shear Resistance Algorithm

All section properties and demands are converted from CSiBridge model units to N, mm.

If the combo specified in the M_u demand set contains envelopes, a new force demand set is generated. The new force demand set is built up from the maximum tension values of P and the maximum absolute values of V2 and M3 of the two StepTypes (Max and Min) present in the envelope COMBO case. The StepType of this new force demand set is named ABS and the signs of the P, V2 and M3 are preserved. The ABS case follows the industry practice where sections are designed for extreme shear and moments that are not necessarily corresponding to the same design vehicle position. The section cut is designed for all three StepTypes in the COMBO—Max, Min and ABS—and the controlling StepType is reported.

In the case when the demand moment $\left|M_u\right| < \left|V_u - V_p\right| \times d_v$, two new force demand sets are generated where $M_{u\text{pos}} = \left|V_u - V_p\right| d_{v\text{pos}}$

and $M_{u\text{neg}} = -\left|V_u - V_p\right| d_{v\text{neg}}$. The acronyms "-CodeMinMuPos" and "-CodeMinMuNeg" are added to the end of the StepType name. The signs of the P and V2 are preserved.

The shear resistance is evaluated for every force demand set described previously and the smallest value is used in evaluation of the rating factor.

- The component in the direction of the applied shear of the effective prestressing force, positive if resisting the applied shear, is evaluated:

$$V_p = \frac{V_{2c} - V_{2\text{Tot}}}{n_{\text{girders}}}$$

- Depth of equivalent stress block '*a*' for both positive and negative moment is evaluated in accordance with eq. 5.7.3.1.1. See section 3.1.2

- Effective shear depth is evaluated.

$$d_e = \frac{A_{ps} f_{ps} d_p + A_{vl} f_y d_s}{A_{ps} f_{ps} + A_{vl} f_y}$$

$$d_v = \max\left(0.72 d_{\text{girder}}, 0.9 d_e, d_e - 0.5a\right)$$

- Evaluate numerator and denominator of (eq. 5.8.3.4.2-4)

$$\varepsilon_{\text{snumerator}} = \frac{\left|M_u\right|}{d_V} + 0.5 \times N_u + \left|V_u - V_p\right| - A_{ps} \times 0.7 \times f_{pu}$$

$$\varepsilon_{\text{sdenominator}} = E_p \times A_{ps} + E_s \times A_{vl}$$

- Adjust denominator values as follows

If $\varepsilon_{\text{sdenominator}} = 0$ and $\varepsilon_{\text{snumerator}} > 0$, then $\varepsilon_s = \varepsilon_{s\text{LimitPos}}$

$$\text{If } \varepsilon_{\text{snumerator}} < 0 \text{ then } \varepsilon_{\text{sdenominator}} = E_p \times A_{ps} + E_s \times A_{vl} + E_c \times A_c$$

- Evaluate (eq. 5.8.3.4.2-4)

$$\varepsilon_s = \frac{\varepsilon_{\text{snumerator}}}{\varepsilon_{\text{sdenominator}}}$$

- Check if axial tension is large enough to crack the flexural compression face of the section.

$$\text{If } \frac{N_u}{A_{\text{girder}}} > 0.52 \times \sqrt{f'_c}\text{, then } \varepsilon_s = 2 \times \varepsilon_s$$

- Check against the limit on the strain in non-prestressed longitudinal tension reinforcement specified in the Design Request

$$\varepsilon_s = \max(\varepsilon_s, \varepsilon_{\text{sLimitNeg}}) \text{ and } \varepsilon_s = \min(\varepsilon_s, \varepsilon_{\text{sLimitPos}})$$

- Evaluate the angle θ of inclination of diagonal compressive stresses as determined in Article 5.8.3.4

$$18 \le 29 + 3500 \times \varepsilon_s \le 45 \qquad (5.8.3.4)$$

- Evaluate minimum transverse reinforcement density required in accordance with the code

$$A_{v\min} = 0.083\lambda\sqrt{f'_c}\,\frac{b_v}{f_y} \qquad (5.8.3.4)$$

- Check if the provided girder transverse reinforcement density $A_{v\text{prov}}$ averaged over distance 0.5 cot θ measured up-station and down-station from the current section cut satisfies minimum specified by code and evaluate the factor β indicating the ability of diagonally cracked concrete to transmit tension and shear, as specified in Article 5.8.3.4

If $A_{v\text{prov}} \ge A_{v\min}$, then $\beta = \frac{4.8}{1 + 750 \times \varepsilon_s}$

else

$$\beta = \frac{4.8}{1+750\varepsilon_s}\frac{51\times 25.4}{39\times 25.4 + s_{xe}}$$

where $s_{xe} = \dfrac{35 s_x}{a_g + 16}$ (eq. 5.8.3.4)

- Evaluate nominal shear resistance provided by tensile stresses in the concrete (eq. 5.8.3.3-3)

$$V_c = 0.083\times\beta\times\lambda\times\sqrt{f'_c}\times b\times d_v$$

- Evaluate nominal shear resistance provided by tensile stresses in the transverse reinforcement (eq. 5.8.3.3-4)

$$V_s = A_{\text{vprov}} f_y d_v \cot\theta \qquad \text{(eq. 5.8.3.3-4)}$$

- Evaluate total factored shear resistance and check against a maximum specified in 5.8.3.3-2

$$V_r = \varphi_v \min\left(V_c + V_s; 0.25 f'_c b_v d_v\right)$$

Note: The shear resistance evaluated here purposely ignores the effect of the component in the direction of the applied shear of the effective prestressing force V_p. This is to ensure that the prestressing effect is not double counted when evaluating the load rating factor. The name of the combo that contains the prestressing loads is specified in the Demand Set “P Combo” in the Rating Request.

3.1.3.7 Rating Factor Algorithm

In case any of the user-defined combos for demands sets $\gamma_{DC}V_{DC}$, $\gamma_{DW}V_{DW}$, or $\gamma_P V_P$ contain multiple StepTypes, the V2 demands from Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting the maximum absolute from the two StepType values while preserving the sign.

The girder rating factor is calculated for each StepType present in the $\gamma_L V_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

The sign of the sum of shear demands $\gamma_{DC} V_{DC}$, $\gamma_{DW} V_{DW}$, or $\gamma_P V_P$ is determined. If the sign of the sum matches the sign of the $\gamma_L V_{LL+IM}$; the shear resistance is reduced by the sum; if the sign of the sum is opposite, the shear resistance is increased by the sum.

Chapter 4 Precast Concrete Girder Bridges with Composite Slabs

This chapter describes the algorithm CSiBridge applies when load rating deck superstructures comprised of precast I or U girders with composite slabs.

This algorithm analyzes the superstructure on a girder-by-girder (beam-by-beam) basis while ignoring the effects of torsion. The user has the option to use the individual girder demands directly from the CSiBridge model (available only for Area and Solid models) or use Live Load Distribution (LLD) factors. CSiBridge gives the user a choice of methods to address distribution of live load to individual girders. The evaluation and application of LLD factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

It is important to note that to obtain relevant results, the definition of a Moving Load case must be adjusted depending on which method is selected. Refer to Chapter 3 Section 3.1 of the *Bridge Superstructure Design* manual.

Legend:

Girder = beam + tributary area of the top of the slab

Section Cut = all girders are present in the cross-section at the cut location

4.1 Load Rating - Flexure

4.1.1 Rating Factor

$$RF = \frac{\varphi M_n - \gamma_{DC} M_{DC} - \gamma_{DW} M_{DW} - \gamma_P M_P}{\gamma_L M_{LL+IM}}$$

AASHTO MBE eq. 6A-4.2.1

RF = Rating factor calculated by CSiBridge

M_n = Nominal moment resistance calculated by CSiBridge

The following values are specified by the user in the Rating Request:

φ = Resistance factor for flexure; Default Value = 1.0, Typical value(s): 1.0. The φ factor is specified in the Rating Parameters form.

$\gamma_{DC} M_{DC}$ = Factored moment demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.

$\gamma_{DW} M_{DW}$ = Factored moment demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.

$\gamma_P M_P$ = Factored moment demand due to permanent loads other than dead loads. The γ_P factor shall be included in the combo specified in the P Combo demand set.

$\gamma_L M_{LL+IM}$ = Factored moment demand due to live load. The γ_L factor shall be included in the combo specified in the LL+IM Combo demand set.

4.1.2 Flexural Resistance

The flexural resistance is determined in accordance with selected AASHTO LRFD edition and applicable interim that were specified in the Bridge Rating Preferences form. Detailed description of resistance calculation is presented in the Bridge Superstructure Design manuals. The resistance is evaluated only for bending about horizontal axis 3. Separate resistance is calculated for positive and negative moment.

The moment resistance is based on bonded tendons and longitudinal mild steel reinforcement defined in the Bridge Object. It is assumed that all defined tendons in a section, stressed or not, have f_{pe} (effective stress after loses) larger than 0.5 f_{pu} (specified tensile strength). If a certain tendon should not be considered for the flexural resistance calculation, its area must be set to zero.

Only reinforcement in the tensile zone of the section is assumed to contribute towards the moment resistance of the section; reinforcement in compression zone is ignored.

4.1.3 Live Load Distribution into Girders

The M3 demands on the section cuts specified in the LL+IM demand set are distributed into individual girders according to the Live Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

M3 demands on the section cut specified in the DC, DW and P Combo demand sets are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders -- available for Area and Solid models only). In that case, the forces from CSiBridge are read directly on a girder-by-girder basis.

4.1.4 Rating Factor Algorithm

In case any of the user-defined combos for demands sets $\gamma_{DC}M_{DC}$, $\gamma_{DW}M_{DW}$, or $\gamma_p M_p$ contain multiple StepTypes, the M3 demands from Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting the maximum absolute from the two StepType values while preserving the sign.

The girder rating factor is calculated for each StepType present in the $\gamma_L M_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

For each StepType, one of the girder flexural capacities (positive or negative) to be used in the rating factor equation is selected to match the sign of the $\gamma_L M_{LL+IM}$ moment. Then the sign of the sum of moments $\gamma_{DC}M_{DC}$, $\gamma_{\mathrm{DW}}\mathrm{M}_{\mathrm{DW}}$, or $\gamma_{\mathrm{p}}\mathrm{M}_{\mathrm{p}}$ is determined. If the sign of the sum matches the sign of the $\gamma_L M_{LL+IM}$, the moment resistance is reduced by the sum; if the sign of the sum is opposite, the moment resistance is increased by the sum.

4.2 Load Rating – Min Rebar for Flexure

In this rating request, CSiBridge verifies if the minimum reinforcement requirement is satisfied in accordance with AASHTO LRFD Section 5.7.3.3.2. The code states that the calculated flexural resistance M_r based on the provided PT and longitudinal rebar must satisfy the following requirement:

$$M_r > \min(1.2M_{cr}, 1.33M_u)$$

where $M_{cr} = S_c\left(f_r + f_{cpe}\right) - M_{dnc}\left(\frac{S_c}{S_{nc}} - 1\right) \geq S_c f_r$ (calculated by CSiBridge)

S_c = Section modulus for the extreme fiber of the composite girder where tensile stress is caused by externally applied loads. The value is calculated by CSiBridge and reported in the output table.

S_{nc} = Section modulus for the extreme fiber of the noncomposite beam where tensile stress is caused by externally applied loads. The value is calculated by CSiBridge and reported in the output table.

f_{cpe} = Compressive stress in concrete due to effective prestress force only (after allowance for all prestress losses) at the extreme fiber of the girder where tensile stress is caused by externally applied loads. The user specifies the name of the combo for the f_{cpe} demand set in the definition of the Bridge Rating Request.

f_r = Modulus of rupture. The user specifies in this value in the Rating Parameters.

M_{dnc} = Total unfactored dead load moment acting on the noncomposite beam. The user specifies the name of the combo for the M_{dnc} demand set in the definition of the Bridge Rating Request.

M_u = Factored moment required by the applicable strength load combinations specified in AASHTO LRFD Table 3.4.1-1. The user specifies the name of the combo for the M_u demand set in the definition of the Bridge Rating Request.

4.2.1 Live Load Distribution into Girders

The M3 demands on the section cut specified in the M_u demand set are distributed into individual girders according to the Live

Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

M3 demands on the section cut specified in the f_{cpe} and M_{dnc} combo demand set are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders – available for Area and Solid models only). In that case, forces from CSiBridge are not read on a section-cut basis but directly on a girder-by-girder basis.

When evaluating min rebar for negative moment, the M_{dnc} is set to zero, since it is assumed that the composite slab is never a noncomposite section.

4.2.2 Min Rebar for Flexure Algorithm

At each girder, the resistances for both positive and negative moments are determined using the procedure outlined in this Section 3.1.2. The f_{cpe} stresses at the top and bottom extreme fiber are read, and the M_{cr} values for both positive and negative moments are evaluated.

For each StepType present in the M_u combo, the sign and magnitude of the M3 moment is read. If the M_u sign is negative, the minimum rebar equation is checked for negative flexural resistance, and if the M_u sign is positive, the minimum rebar equation is checked for positive flexural resistance. If both StepTypes present in the M_u combo have the same sign, the minimum rebar for the opposite sign moment is not checked, and the note “Not applicable” is reported in the output table.

4.3 Load Rating - Shear

4.3.1 Rating Factor

$$RF = \frac{\varphi V_n - \gamma_{DC} V_{DC} - \gamma_{DW} V_{DW} - \gamma_p V_p}{\gamma_L V_{LL+IM}}$$

AASHTO MBE eq. 6A-4.2.1

RF = Rating factor calculated by CSiBridge

V_n = Nominal shear resistance calculated by CSiBridge

The user specifies the values for the following in the Rating Request:

φ = Resistance factor for shear; Default Value = 0.9, Typical value(s): 0.9 for normal weight concrete, 0.7 for light-weight concrete. The φ factor is specified in the Rating Parameters form.

$\gamma_{DC}V_{DC}$ = Factored shear demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.

$\gamma_{DW}V_{DW}$ = Factored shear demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.

$\gamma_P V_P$ = Factored shear demand due to permanent loads other than dead loads. The γ_P factor shall be included in the combo specified in the P Combo demand set.

$\gamma_L V_{LL+IM}$ = Factored shear demands due to live load. The γ_L factor shall be included in the combo specified in the LL+IM Combo demand set.

4.3.2 Live Load Distribution into Girders

The *V*2 demands on the section cut specified in the *LL+IM* and M_u demand set are distributed into individual girders according to the Live Load Distribution method specified in the Rating Request. The evaluation and application of live load distribution factors is described in detail in Chapter 3 of the *Bridge Superstructure Design* manual.

*V*2 demands on the section cut specified in the DC, DW and P Combo demand sets are distributed evenly to all girders unless live load distribution Method 3 is used (CSiBridge reads the calculated live load demands directly from individual girders – available for Area and Solid models only). In that case, forces from CSiBridge are read directly on a girder-by-girder basis.

4.3.3 Shear Resistance

The shear resistance is determined in accordance with selected AASHTO LRFD edition and applicable interim that were specified in the Bridge Rating Preferences form. Detailed description of resistance calculation is also presented in the Bridge Superstructure Design manuals.

The shear resistance is determined in accordance with paragraph 5.8.3.4.2 (derived from Modified Compression Field Theory). The procedure assumes that the concrete shear stresses are distributed uniformly over an area b_v wide and d_v deep, that the direction of principal compressive stresses (defined by angle θ and shown as D) remains constant over d_v, and that the shear strength of the section can be determined by considering the biaxial stress conditions at just one location in the web. The user should select for design only those sections that comply with these assumptions by defining appropriate station ranges in the design request (see Chapter 4 of the *Bridge Superstructure Design* manual).

It is assumed that the precast beams are pre-tensioned, and therefore, no ducts are present in webs. The effective web width is taken as the minimum web width, measured parallel to the neutral axis, between the resultants of the tensile and compressive forces as a result of flexure

Shear design is completed on a per-web (girder) basis; torsion is ignored.

Transverse reinforcement specified in the Bridge Object is used to verify if minimum shear reinforcement is provided. It is also used to calculate V_s shear resistance component. The density (area per unit length) of provided transverse reinforcement in a given girder is averaged based on values specified in the Bridge Object over distance 0.5 $d_v \cot\theta$ measured down-station and up-station from a given section cut

4.3.4 Shear Resistance Parameters

The following parameters are considered during shear design:

- M_u Combo Demand Set – the forces in the specified combo are used in the Modified Compression Field Theory (MCFT) equations to determine shear resistance of the girder

- *PhiC* – Resistance Factor; Default Value = 0.9, Typical value(s): 0.7 to 0.9. The nominal shear resistance of normal weight concrete sections is multiplied by the resistance factor to obtain factored resistance.

- *PhiC* (*Lightweight*) – Resistance Factor for light-weight concrete; Default Value = 0.7, Typical value(s): 0.7 to 0.9. The nominal shear resistance of light-weight concrete sections is multiplied by the resistance factor to obtain factored resistance.

- *Check Sub Type* – Typical value: MCFT. Specifies which method for shear design will be used: either MCFT in accordance with 5.8.3.4.2; or the V_{ci}/V_{cw} method in accordance with 5.8.3.4.3 Currently only the MCFT option is available.

- *Negative limit on strain in nonprestressed longitudinal reinforcement* in accordance with section 5.8.3.4.2; Default Value = $-0.4\text{x}10^{-3}$, Typical value(s): 0 to $-0.4\text{x}10^{-3}$

- *Positive limit on strain in nonprestressed longitudinal reinforcement* in accordance with section 5.8.3.4.2; Default Value = $6.0\text{x}10^{-3}$, Typical value(s): $6.0\text{x}10^{-3}$

- *PhiC for N_u* – Resistance Factor used in equation 5.8.3.5-1; Default Value = 1.0, Typical value(s): 0.75 to 1.0

- *Phif for M_u* – Resistance Factor used in equation 5.8.3.5-1; Default Value = 0.9, Typical value(s): 0.9 to 1.0

- *sx* = Maximum distance between layers of longitudinal crack control reinforcement in accordance with AASHTO LRFD 5.8.3.4.2-5. This parameter is used only when a girder does not contain the code-specified minimum amount of shear reinforcement.

- *ag* = Maximum aggregate size, Eq 5.8.3.4.2. This parameter is used only when a girder does not contain the code-specified minimum amount of shear reinforcement.

4.3.5 Shear Resistance Variables

A_c = Area of concrete on the flexural tension side of the member

A_{ps} = Area of prestressing steel on the flexural tension side of the member

A_{vl} = Area of nonprestressed steel on the flexural tension side of the member at the section under consideration

$A_{v\text{prov}}$ = Area of transverse shear reinforcement per unit length as specified in the Bridge Object. The transverse reinforcement density is averaged over a distance 0.5 cotθ measured up-station and down-station from the current section cut.

$A_{VS\,\mathrm{min}}$ = Minimum area of transverse shear reinforcement per unit length in accordance with eq. 5.8.2.5

E_c = Young’s modulus of beam concrete

E_p = Prestressing steel Young’s modulus

E_s = Reinforcement Young’s modulus

M_u = Factored moment at the section

N_u = Applied factored axial force, taken as positive if tensile

$V_{2\mathrm{c}}$ = Shear in section cut excluding force in tendons

$V_{2\mathrm{Tot}}$ = Shear in section cut including force in tendons

V_p = Component in the direction of the applied shear of the effective prestressing force; if V_p has the same sign as V_u, then the component is resisting the applied shear

V_u = Factored shear demand per girder excluding force in tendons

a = Depth of equivalent stress block in accordance with 5.7.3.2.2. Varies for positive and negative moment.

b = Minimum web width

d_{compslab} Depth of composite slab (includes concrete haunch t2)

d_{girder} = Depth of girder

d_p = Distance from compression face to center of gravity of tendons in the tensile zone

d_s = Distance from compression face to center of gravity of longitudinal reinforcement in the tensile zone

d_v = Effective shear depth in accordance with 5.8.2.9

f_{pu} = Specified tensile strength of prestressing steel

$\varepsilon_{s\text{LimitPos}}, \varepsilon_{s\text{LimitNeg}}$ = Max and min value of strain in nonprestressed longitudinal tension reinforcement as specified in the Design Request

ε_s = Strain in nonprestressed longitudinal tension reinforcement – eq. 5.8.3.4.2-4

ϕ_F = Resistance factor for moment

ϕ_P = Resistance factor for axial load

ϕ_V = Resistance factor for shear

λ = Multiplier of $\sqrt{f'_c}$ for light-weight concrete in accordance with 5.8.2.2

4.3.6 Shear Resistance Algorithm

All section properties and demands are converted from CSiBridge model units to N, mm.

If the combo specified in the M_u demand set contains envelopes, a new force demand set is generated. The new force demand set is built up from the maximum tension values of P and the maximum absolute values of V2 and M3 of the two StepTypes (Max and Min) present in the envelope COMBO case. The StepType of this new force demand set is named ABS and the signs of the P, V2, and M3 are preserved. The ABS case follows the industry practice where sections are designed for extreme shear and moments that are not necessarily corresponding to the same design vehicle position. The section cut is designed for all three StepTypes in the COMBO—Max, Min and ABS—and the controlling StepType is reported.

In the case when demand moment $|M_u| < |V_u - V_p| \times d_v$, two new force demand sets are generated where $M_{upos} = |V_u - V_p| d_{vpos}$ and $M_{uneg} = -|V_u - V_p| d_{vneg}$. The acronyms “-CodeMinMuPos” and “-CodeMinMuNeg” are added to the end of the StepType name. The signs of the P and V2 are preserved.

- The shear resistance is evaluated for every force demand set described previously. and the smallest value is used in evaluation of the rating factor.
- The component in the direction of the applied shear of the effective prestressing force, positive if resisting the applied shear, is evaluated:

$$V_p = \frac{V_{2c} - V_{2\text{Tot}}}{n_{\text{girders}}}$$

- Depth of equivalent stress block ‘*a*’ for both positive and negative moment is evaluated in accordance with eq. 5.7.3.1.1. See section 4.1.2.
- Effective shear depth is evaluated.

$$d_e = \frac{A_{ps} f_{ps} d_p + A_{vl} f_y d_s}{A_{ps} f_{ps} + A_{vl} f_y}$$

$$d_v = \max\left(0.72 d_{\text{girder}}, 0.9 d_e, d_e - 0.5a\right)$$

- Evaluate numerator and denominator of (eq. 5.8.3.4.2-4)

$$\varepsilon_{\text{snumerator}} = \frac{|M_u|}{d_V} + 0.5 \times N_u + \left|V_u - V_p\right| - A_{ps} \times 0.7 \times f_{pu}$$

$$\varepsilon_{\text{sdenominator}} = E_p \times A_{ps} + E_s \times A_{vl}$$

- Adjust denominator values as follows

If $\varepsilon_{\text{sdenominator}} = 0$ and $\varepsilon_{\text{snumerator}} > 0$, then $\varepsilon_s = \varepsilon_{\text{sLimitPos}}$

If $\varepsilon_{\text{snumerator}} < 0$, then $\varepsilon_{\text{sdenominator}} = E_p \times A_{ps} + E_s \times A_{vl} + E_c \times A_c$

- Evaluate (eq. 5.8.3.4.2-4)

$$\varepsilon_s = \frac{\varepsilon_{s\text{numerator}}}{\varepsilon_{s\text{denominator}}}$$

- Check if axial tension is large enough to crack the flexural compression face of the section.

$$\text{If } \frac{N_u}{A_{\text{girder}}} > 0.52 \times \sqrt{f'_c}\text{, then } \varepsilon_s = 2 \times \varepsilon_s$$

- Check against the limit on the strain in non-prestressed longitudinal tension reinforcement specified in the Design Request

$$\varepsilon_s = \max(\varepsilon_s, \varepsilon_{s\text{LimitNeg}}) \text{ and } \varepsilon_s = \min(\varepsilon_s, \varepsilon_{s\text{LimitPos}})$$

- Evaluate the angle θ of inclination of diagonal compressive stresses as determined in Article 5.8.3.4

$$18 \le 29 + 3500 \times \varepsilon_s \le 45 \qquad (5.8.3.4)$$

- Evaluate minimum transverse reinforcement density required in accordance with code

$$A_{v\min} = 0.083\lambda\sqrt{f'_c}\,\frac{b_v}{f_y} \qquad (5.8.3.4)$$

- Check if the provided girder transverse reinforcement density $A_{v\text{prov}}$ averaged over distance 0.5cotθ measured up-station and down-station from the current section cut satisfies the minimum specified by code and evaluate the factor β indicating the ability of diagonally cracked concrete to transmit tension and shear, as specified in Article 5.8.3.4

  - If $A_{v\text{prov}} \ge A_{v\min}$, then $\beta = \frac{4.8}{1 + 750 \times \varepsilon_s}$

    else

$$\beta = \frac{4.8}{1 + 750\varepsilon_s} \frac{51 \times 25.4}{39 \times 25.4 + s_{xe}}$$

$$\text{where } s_{xe} = \frac{35 s_x}{a_g + 16} \qquad \text{(eq. 5.8.3.4)}$$

- Evaluate nominal shear resistance provided by tensile stresses in the concrete eq. 5.8.3.3-3

$$V_c = 0.083 \times \beta \times \lambda \times \sqrt{f'_c} \times b \times d_v$$

- Evaluate nominal shear resistance provided by tensile stresses in the transverse reinforcement eq. 5.8.3.3-4

$$V_s = A_{\text{vprov}} f_y d_v \cot\theta \qquad \text{(eq. 5.8.3.3-4)}$$

- Evaluate total factored shear resistance and check against a maximum specified in 5.8.3.3-2

$$V_r = \varphi_v \min\left(V_c + V_s;\ 0.25 f'_c b_v d_v\right)$$

Note: The shear resistance evaluated here purposely ignores the effect of the component in the direction of the applied shear of the effective prestressing force V_P. This is to ensure that the prestressing effect is not double counted when evaluating the load rating factor. The name of the combo that contains the prestressing loads is specified in the Demand Set “P Combo” in the rating request.

4.3.7 Rating Factor Algorithm

In case any of the user-defined combos for demands sets $\gamma_{DC}V_{DC}$, $\gamma_{DW}V_{DW}$, or $\gamma_P V_P$ contain multiple StepTypes, the V2 demands from Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting maximum absolute from the two StepType values while preserving the sign.

The girder rating factor is calculated for each StepType present in the $\gamma_L V_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

The sign of the sum of shear demands $\gamma_{DC} V_{DC}$, $\gamma_{DW} V_{DW}$, or $\gamma_P V_P$ is determined. If the sign of the sum matches the sign of the $\gamma_L V_{LL+IM}$, the shear resistance is reduced by the sum; if the sign of the sum is opposite, the shear resistance is increased by the sum.

Chapter 5 Steel I-Section with Concrete Slab

This chapter describes the algorithm CSiBridge applies when load rating deck superstructures comprised of steel I-beam with concrete slab. The slab can be non-composite or composite. The user has an option to set determination of flexural capacity of qualifying sections in accordance with AASHTO LRFD Section 6 or with Appendix A.

This algorithm analyzes the superstructure on a girder-by-girder (beam-by-beam) basis while ignoring the effects of torsion. The user has the option to use the individual girder demands directly from the CSiBridge model (available only for Area and Solid models) or use Live Load Distribution (LLD) factors. CSiBridge gives the user a choice of methods to address distribution of live load to individual girders. The evaluation and application of LLD factors is described in detail in Chapter 3 of the Bridge Superstructure Design manual. It is important to note that to obtain relevant results, the definition of a Moving Load case must be adjusted depending on which method is selected. Refer to Chapter 3 Section 3.1 of the *Bridge Superstructure Design* manual.

5.1 Load Rating

5.1.1 Rating Factor

$$RF = \frac{(\varphi_c)(\varphi_s)(\varphi)R_n - (\gamma_{\mathrm{DC}})(\mathrm{DC}) - (\gamma_{\mathrm{DW}})(\mathrm{DW})}{(\gamma_{\mathrm{L}})(\mathrm{LL} + \mathrm{IM})}$$

AASHTO MBE. 6A-4.2.1

RF	Rating factor calculated by CSiBridge
R_n	Nominal resistance calculated by CSiBridge

Values specified by the user in the Rating Request:

φ_c	Condition factor; Default Value = 1.0, Typical value(s): 1.0. The factor is specified in the Rating Parameters form.
φ_s	System factor; Default Value = 1.0, Typical value(s): 1.0. The factor is specified in the Rating Parameters form.
φ	Resistance factor taken as φ_{flex} or φ_{shear} depending on type of rating
φ_{flex}	Resistance factor for flexure; Default Value = 1.0, Typical value(s): 1.0. The factor is specified in the Rating Parameters form.
φ_{shear}	Resistance factor for shear; Default Value = 1.0, Typical value(s): 1.0. The factor is specified in the Rating Parameters form.
$\gamma_{DC}DC$	Factored moment demand due to dead load of structural components and attachments. The γ_{DC} factor shall be included in the combo specified in the DC Combo demand set.
$\gamma_{DW}DW$	Factored moment demand due to dead load of wearing surface and utilities. The γ_{DW} factor shall be included in the combo specified in the DW Combo demand set.
LLIM	Factored demand due to live load. The γ_L factor shall be included in the combo specified in the LL+IM Combo demand set.

5.1.2 Rating Factor Algorithm - Flexure

The rating factor is calculated for each StepType present in the γ_LLLIM demand set. The StepType that produces the smallest rating factor is reported in the output table.

For each StepType one of the sections flexural capacities (positive or negative) to be used in the rating factor equation is selected to match the sign of the γ_LLLIM moment. Then the sign of the sum of moments $\gamma_{DC}DC + \gamma_{DW}DW$ is determined. If the sign of the sum matches the sign of the γ_LLLIM, the moment resistance is reduced by the sum; if the sign of the sum is opposite, the moment resistance is increased by the sum.

When the AASHTO LRFD code prescribes flange lateral bending stresses f_l to be considered, the specified fraction of the absolute value of f_l caused by DC and DW is deducted from resistance, and f_l caused by LLIM is added to the LLIM demand.

5.1.3 Rating Factor Algorithm - Shear

In case any of the user defined combos for demands sets $\gamma_{DC}V_{DC}$ or $\gamma_{DW}V_{DW}$ contain multiple StepTypes, the $V2$ demands from the Max and Min StepTypes are consolidated into one ABS StepType. This is accomplished by selecting the maximum absolute from the two StepType values while preserving the sign.

The girder rating factor is calculated for each StepType present in the $\gamma_L V_{LL+IM}$ demand set. The StepType that produces the smallest rating factor is reported in the output table.

The sign of the sum of shear demands $\gamma_{DC}V_{DC}$ + $\gamma_{DW}V_{DW}$ is determined. If the sign of the sum matches the sign of the $\gamma_L V_{LL+IM}$, the shear resistance is reduced by the sum; if the sign of the sum is opposite the sign of the $\gamma_L V_{LL+IM}$, the shear resistance is increased by the sum.

5.2 Section Properties

5.2.1 Section Proportions

When the rating parameter “Ignore Proportion Limits = No,” the program verifies each section cut for cross-section proportion limits in accordance with AASHTO LRFD Section 6.10.2. If any of the girders in the section cut do not satisfy the limits, the section cut is flagged as not valid, and the rating is not calculated at that cut. To avoid flagging the section as not valid, set the rating parameter to “Yes.” In that case, it is the responsibility of the user to verify that the resistance formulas, as specified in AASHTO LRFD Section 6.10, are still applicable.

5.2.2 Yield Moments

5.2.2.1 Composite Section in Positive Flexure

The positive yield moment, M_y, is determined by the program in accordance with section D6.2.2 of the code. For the purpose of determining positive yield moment, M_y, the program decomposes load cases present in combo DC to two Bridge Design Action categories: non-composite and composite long term; all load cases present in DW are assigned to the composite long-term category. The program uses the load case Bridge Design Action parameter to assign the load cases to the appropriate categories. It should be noted that any Non-Linear Staged Analysis case present in the DC combo will be assigned to the non-composite category. See Section 5.2.5 for more information on the Bridge Design Action categories.

M_{dnc} = Moment caused by the factored permanent load applied before the concrete deck has hardened or is made composite.

M_{dc} = Moment caused by the remainder of the factored permanent load (applied to the composite section).

The program solves for M_{AD} from the following equation,

$$F_{yt} = \frac{M_{dnc}}{S_{NC}} + \frac{M_{dc}}{S_{LT}} + \frac{M_{AD}}{S_{ST}} \qquad \text{(D6.2.2-1)}$$

and then calculates yield moment based on the following equation

$$M_y = M_{dnc} + M_{dc} + M_{AD} \qquad \text{(D6.2.2-2)}$$

where

S_{NC} = Noncomposite section modulus (in.^{3})

S_{LT} = Long-term composite section modulus (in.^{3})

S_{ST} = Short-term composite section modulus (in.^{3})

M_y is taken as the lesser value calculated for the compression flange, M_{yc}, or the tension flange, M_{yt}. It should be noted that the M_y calculated in the procedure described here is used by the program only to determine M_{npos} for compact section in positive bending in a continuous span, where the nominal flexural resistance may be controlled by M_y in accordance with (eq. 6.10.7.1.2-3).

$$M_n \le 1.3 R_h M_y$$

5.2.2.2 Composite Section in Negative Flexure

For composite sections in negative flexure, the procedure described for positive yield moment is followed, except that the composite section for both short-term and long-term moments consist of the steel section and the longitudinal reinforcement within the tributary width of the concrete deck. Thus, S_{ST} and S_{LT} are the same value. Also, M_{yt} is taken with respect to either the tension flange or the longitudinal reinforcement, whichever yields first.

It should be noted that the M_y calculated in the procedure described here is used by the program solely to determine the limiting slenderness ratio for a compact web corresponding to $2D_{cp}/t_w$ in (eq. A6.2.1-2).

$$\lambda_{pw(D_{cp})} = \frac{\sqrt{\dfrac{E}{F_{yc}}}}{\left(0.54\dfrac{M_p}{R_h M_y} - 0.09\right)^2} \le \lambda_{rw}\left(\frac{D_{cp}}{D_c}\right) \tag{A6.2.1-2}$$

and web plastification factors in (eqs. A.6.2.2-4 and A6.2.2-5).

$$R_{pc} = \left[1 - \left(1 - \frac{R_h M_{yc}}{M_p}\right)\left(\frac{\lambda_w - \lambda_{pw(D_c)}}{\lambda_{rw} - \lambda_{pw(D_c)}}\right)\right]\frac{M_p}{M_{yc}} \le \frac{M_p}{M_{yc}} \tag{A.6.2.2-4}$$

$$R_{pt} = \left[1 - \left(1 - \frac{R_h M_{yt}}{M_p}\right)\left(\frac{\lambda_w - \lambda_{pw(D_c)}}{\lambda_{rw} - \lambda_{pw(D_c)}}\right)\right]\frac{M_p}{M_{yt}} \le \frac{M_p}{M_{yt}} \tag{A6.2.2-5}$$

5.2.2.3 Non-Composite Section

The yield moment, M_y, of a non-composite section is taken as the smaller of the moment required to cause nominal first yielding in the compression flange, M_{yc}, and the moment required to cause nominal first yielding in the tension flange, M_{yt}, at the strength limit state. Flange lateral bending in all types of sections and web yielding in hybrid sections is disregarded in this calculation.

$$M_{yt} = F_{yt} S_t$$

$$M_{yc} = F_{yc} S_c$$

$$M_y = \min(M_{yt}, M_{yc})$$

5.2.3 Plastic Moments

5.2.3.1 Composite Section in Positive Flexure

The positive plastic moment, M_p, is calculated as the moment of the plastic forces about the plastic neutral axis. Plastic forces in the steel portions of a cross-section are calculated using the yield strengths of the flanges, the web, and reinforcing steel, as appropriate. Plastic forces in the concrete portions of the cross-section that are in compression are based on a rectangular stress block with the magnitude of the compressive stress equal to 0.85 f_c'. Concrete in tension is neglected. The position of the plastic neutral axis is determined by the equilibrium condition that there is no net axial force.

The plastic moment of a composite section in positive flexure is determined by:

- Calculating the element forces and using them to determine if the plastic neutral axis is in the web, top flange, or concrete deck;
- Calculating the location of the plastic neutral axis within the element determined in the first step;

  and

- Calculating *Mp*.

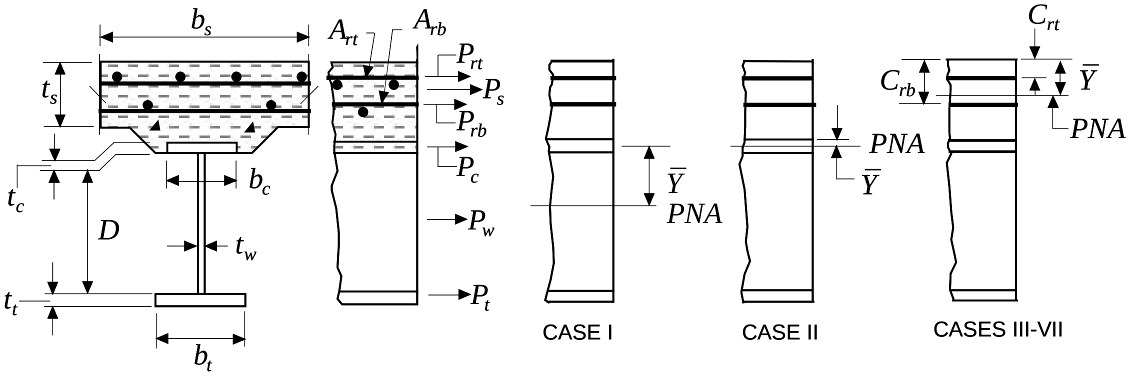
Equations for the various potential locations of the plastic neutral axis (PNA) are given in Table 5-1.

Table 5-1 Calculation of PNA and M_p for Sections in Positive Flexure

Case	**PNA**	**Condition**	$\bar{Y}$ **and** M_p
I	In Web	$P_t + P_w \geq P_c + P_s + P_{rb} + P_n$	$\bar{Y} = \left(\frac{D}{2}\right)\left[\frac{P_t - P_c - P_s - P_{rt} - P_{rb}}{P_w} + 1\right]$ $M_p = \frac{P_w}{2D}\left[\bar{Y}^2 + \left(D - \bar{Y}\right)^2\right] + \left[P_s d_s + P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_t d_t\right]$

Table 5-1 Calculation of PNA and M_p for Sections in Positive Flexure

Case	PNA	Condition	$\bar{Y}$ and M_p
II	In Top Flange	$P_t + P_w + P_c \geq P_s + P_{rb} + P_n$	$\bar{Y} = \left(\frac{t_c}{2}\right)\left[\frac{P_w + P_t - P_s - P_{rt} - P_{rb}}{P_c} + 1\right]$ $M_p = \frac{P_c}{2t_c}\left[\bar{Y}^2 + \left(t_c - \bar{Y}\right)^2\right] + \left[P_s d_s + P_n d_n + P_{rb} d_{rb} + P_w d_w + P_t d_t\right]$
III	Concrete Deck Below P_{rb}	$P_t + P_w + P_c \geq \left(\frac{c_{rb}}{t_2}\right) P_s + P_{rb} + P_n$	$\bar{Y} = \left(t_s\right)\left[\frac{P_c + P_w + P_t - P_{rt} - P_{rb}}{P_s}\right]$ $M_p = \left(\frac{\bar{Y}^2 P_s}{2t_s}\right) + \left[P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$
IV	Concrete Deck at P_{rb}	$P_t + P_w + P_c + P_{rb} \geq \left(\frac{c_{rb}}{t_s}\right) P_s + P_n$	$\bar{Y} = c_{rb}$ $M_p = \left(\frac{\bar{Y}^2 P_s}{2t_s}\right) + \left[P_{rt} d_{rt} + P_c d_c + P_w d_w + P_t d_t\right]$
V	Concrete Deck Above P_{rb} and Below P_{rt}	$P_t + P_w + P_c + P_{rb} \geq \left(\frac{c_{rt}}{t_s}\right) P_s + P_n$	$\bar{Y} = \left(t_s\right)\left[\frac{P_{rb} + P_c + P_w + P_t - P_{rt}}{P_s}\right]$ $M_p = \left(\frac{\bar{Y}^2 P_s}{2t_s}\right) + \left[P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$
VI	Concrete Deck at P_{rt}	$P_t + P_w + P_c + P_{rb} + P_n \geq \left(\frac{c_{rt}}{t_s}\right) P_s$	$\bar{Y} = c_{rt}$ $M_p = \left(\frac{\bar{Y}^2 P_s}{2t_s}\right) + \left[P_{rb} d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$
VII	Concrete Deck Above P_{rt}	$P_t + P_w + P_c + P_{rb} + P_{rt} < \left(\frac{c_{rt}}{t_s}\right) P_s$	$\bar{Y} = \left(t_s\right)\left[\frac{P_{rb} + P_c + P_w + P_t + P_{rt}}{P_s}\right]$ $M_p = \left(\frac{\bar{Y}^2 P_s}{2t_s}\right) + \left[P_{rt} d_{rt} + P_{rb} d_{rb} + P_c d_c + P_w d_w + P_t d_t\right]$



Next the section is checked for ductility requirement in accordance with (eq. 6.10.7.3)

$$D_p \leq 0.42D_t$$

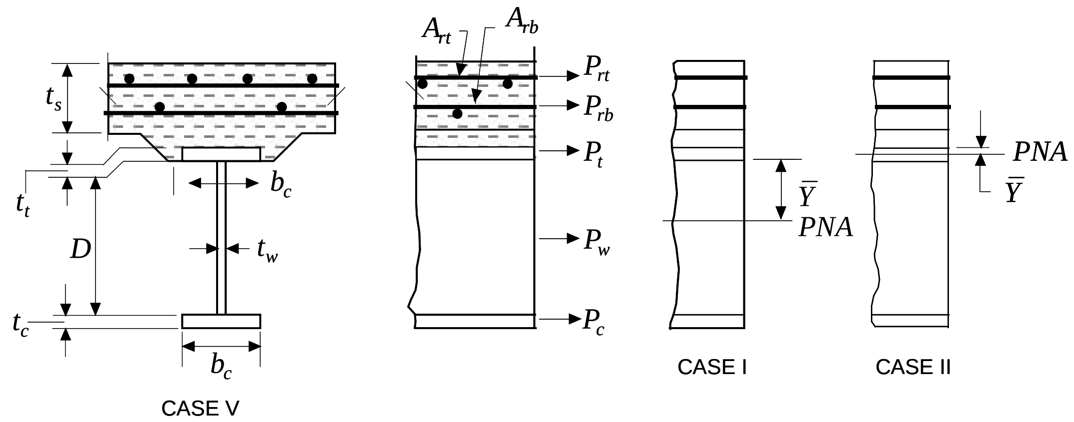
where D_p is the distance from the top of the concrete deck to the neutral axis of the composite section at the plastic moment, and D_t is the total depth of the composite section. At the section where the ductility requirement is not satisfied, the plastic moment of a composite section in positive flexure is set to zero.

5.2.3.2 Composite Section in Negative Flexure

The plastic moment of a composite section in negative flexure is calculated by an analogous procedure. Equations for the two cases most likely to occur in practice are given in Table 5-2.

Table 5-2 Calculation of PNA and M_p for Sections in Negative Flexure

Case	PNA	Condition	$\bar{Y}$ and M_p
I	In Web	$P_c + P_w \geq P_t + P_{rb} + P_n$	$\bar{Y} = \left(\frac{D}{2}\right)\left[\frac{P_c - P_t - P_{rt} - P_{rb}}{P_w} + 1\right]$ $M_p = \frac{P_w}{2D}\left[\bar{Y}^2 + \left(D - \bar{Y}\right)^2\right] + \left[P_n d_n + P_{rb} d_{rb} + P_t d_t + P_l d_l\right]$
II	In Top Flange	$P_c + P_w + P_t \geq P_{rb} + P_n$	$\bar{Y} = \left(\frac{t_l}{2}\right)\left[\frac{P_w - P_c - P_{rt} - P_{rb}}{P_t} + 1\right]$ $M_p = \frac{P_t}{2t_l}\left[\bar{Y}^2 + \left(t_l - \bar{Y}\right)^2\right] + \left[P_n d_n + P_{rb} d_{rb} + P_w d_w + P_c d_c\right]$



in which

$P_{rt} = F_{yrt} A_{rt}$
$P_s = 0.85\, f_c' b_s t_s$
$P_{rb} = F_{yrb} A_{rb}$
$P_c = F_{yc} b_c t_c$
$P_w = F_{yw} D t_w$
$P_t = F_{yt} b_t t_t$

In the equations for M_p given in Tables 5-1 and 5-2, d is the distance from an element force to the plastic neutral axis. Element forces act at (a) mid-thickness for the flanges and the concrete deck, (b) mid-depth of the web, and (c) center of reinforcement. All element forces, dimensions, and distances are taken as positive. The conditions are checked in the order listed in Tables 5-1 and 5-2.

5.2.3.3 Non-Composite Section

The plastic moment of a non-composite section is calculated by eliminating the terms pertaining to the concrete deck and longitudinal reinforcement from the equations in Tables 5-1 and 5-2 for composite sections.

5.2.4 Section Classification and Factors

5.2.4.1 Compact or Non-Compact – Positive Flexure

The program determines if the section can be qualified as compact based on the following criteria:

- the specified minimum yield strengths of the flanges do not exceed 70.0 ksi,
- the web satisfies the requirement of Article (6.10.2.1.1),

$$\frac{D}{t_w} \leq 150$$

- the section satisfies the web slenderness limit,

$$\frac{2D_{cp}}{t_w} \leq 3.76\sqrt{\frac{E}{F_{yc}}}. \tag{6.10.6.2.2-1}$$

The program does not verify if the composite section is kinked (chorded) continuous or horizontally curved.

5.2.4.2 Design in Accordance with Appendix A

The program determines if a section qualifies to be designed using Appendix A of AASHTO LRFD based on the following criteria:

- The Rating Request parameter “Use Appendix A?” is set to Yes (see Chapter 4 for more information about setting parameters in the Rating Request),
- The specified minimum yield strengths of the flanges do not exceed 70.0 ksi,

- The web satisfies the noncompact slenderness limit,

$$\frac{2D_c}{t_w} < 5.7\sqrt{\frac{E}{F_{yc}}} \qquad (6.10.6.2.3\text{-}1)$$

- The flanges satisfy the following ratio,

$$\frac{I_{yc}}{I_{yt}} \geq 0.3. \qquad (6.10.6.2.3\text{-}2)$$

The program does not verify if the composite section is kinked (chorded) continuous or horizontally curved.

5.2.4.3 Hybrid Factor R_h – Composite Section Positive Flexure

For rolled shapes, homogenous built-up sections, and built-up sections with a higher-strength steel in the web than in both flanges, R_h is taken as 1.0. Otherwise the hybrid factor is taken as:

$$R_h = \frac{12+\beta\left(3\rho-\rho^3\right)}{12+2\beta} \qquad (6.10.1.10.1\text{-}1)$$

where

$$\beta = \frac{2D_n t_w}{A_{fn}} \qquad (6.10.1.10.1\text{-}2)$$

ρ = the smaller of F_{yw}/f_n and 1.0

A_{fn} = bottom flange area

D_n = the distance from the elastic neutral axis of the cross-section to the inside face of the bottom flange.

F_n = f_y of the bottom flange.

5.2.4.4 Hybrid Factor R_h – Composite Section Negative Flexure

For rolled shapes, homogenous built-up sections, and built-up sections with a higher-strength steel in the web than in both flanges, R_h is taken as 1.0. Otherwise the hybrid factor is taken as:

$$R_h = \frac{12 + \beta\left(3\rho - \rho^3\right)}{12 + 2\beta} \qquad (6.10.1.10.1\text{-}1)$$

where

$$\beta = \frac{2D_n t_w}{A_{fn}} \qquad (6.10.1.10.1\text{-}2)$$

ρ = the smaller of F_{yw} / f_n and 1.0

A_{fn} = Flange area on the side of the neutral axis corresponding to D_n. If the top flange controls, then the area of longitudinal rebar in the slab is included in calculating A_{fn}.

D_n = The larger of the distances from the elastic neutral axis of the cross-section to the inside face of either flange. For sections where the neutral axis is at the mid-depth of the web, this distance is from the neutral axis to the inside face of the flange on the side of the neutral axis where yielding occurs first.

F_n = f_y of the controlling flange. When the top flange controls, then F_n is equal to the largest of the minimum specified yield strengths of the top flange or longitudinal rebar in the slab.

5.2.4.5 Hybrid Factor R_h – Non-Composite Section

For rolled shapes, homogenous built-up sections, and built-up sections with a higher-strength steel in the web than in both flanges, R_h is taken as 1.0. Otherwise the hybrid factor is taken as:

$$R_h = \frac{12 + \beta\left(3\rho - \rho^3\right)}{12 + 2\beta} \qquad (6.10.1.10.1\text{-}1)$$

where

$$\beta = \frac{2D_n t_w}{A_{fn}} \tag{6.10.1.10.1-2}$$

ρ = the smaller of $F_{yw} \big/ f_n$ and 1.0

A_{fn} = Flange area on the side of the neutral axis corresponding to D_n.

D_n = The larger of the distances from the elastic neutral axis of the cross-section to the inside face of either flange. For sections where the neutral axis is at the mid-depth of the web, this distance is from the neutral axis to the inside face of the flange on the side of the neutral axis where yielding occurs first.

F_n = f_y of the controlling flange.

5.2.4.6 Web Load-Shedding Factor R_b

When rating composite sections in positive flexure, the R_b factor is taken as equal to 1.0. For composite sections in negative flexure and non-composite sections, the R_b factor is taken as:

$$R_b = 1 - \left(\frac{a_{wc}}{1200 + 300_{a_{wc}}} \right) \left(\frac{2D_c}{t_w} - \lambda_{rw} \right) \le 1.0 \tag{6.10.1.10.2}$$

where

$$\lambda_{rw} = 5.7 \sqrt{\frac{E}{F_{yc}}} \tag{6.10.1.10.2-4}$$

$$a_{wc} = \frac{2D_c t_w}{b_{fc} t_{fc}} \tag{6.10.1.10.2-5}$$

When the user specifies the Rating Request parameter “Do webs have longitudinal stiffeners?” as Yes, the R_b factor is set to 1.0 (see Chapter 4 for more information about specifying Rating Request parameters).

5.2.5 Unbraced Length L_b and Section Transitions

The program assumes that the top flange is continuously braced for both the non-composite and composite rating request. The unbraced length L_b for the bottom flange is equal to the distance between the nearest downstation and upstation qualifying cross diaphragms or span support as defined in the Bridge Object. Some of the diaphragm types available in CSiBridge may not necessarily provide restraint to the bottom flange. The program assumes that the following diaphragm qualifies as providing lateral restraint to the bottom flange: single beam, all types of chords and braces except V braces without bottom beam.

For unbraced lengths where the member is nonprismatic, the lateral torsional buckling resistance of the compression flange at each section within the unbraced length is taken as the smallest resistance within the unbraced length under consideration and the moment gradient modifier Cb is taken as 1.0.

For unbraced lengths containing a transition to a smaller section at a distance less than or equal to 20% of the unbraced length from a brace point, the lateral torsional buckling resistance is determined assuming the transition to the smaller section does not exist provided that the lateral moment of inertia of the flange of the smaller section is equal to or larger than 0.5 the corresponding value in the larger section. The algorithm does not distinguish at which brace point the moment demand is smaller and applies the exception at both brace points. It is the responsibility of the user to pay special attention to the section transition within the 20% of the unbraced length from the brace point and to follow the guidelines in AAASHTO LRFD C6.10.8.2.3.

For this algorithm to be effective, it is necessary to have bridge section cuts at each nonprismatic girder-section transition. This can be assured by using the local section cuts feature when updating the linked model to create additional local sections cuts for each girder of steel I-girder bridge sections. Such girder-only section cuts will be created at changes in the steel I-girder section, at staggered diaphragms (cross frames), and at splice locations wherever a full-width section cut does not exist.

5.3 Demand Sets

5.3.1 Composite Sections

The way the demands DW, DC, and LLIM are used depends on the setting of the rating parameter "Use Stage Analysis?" (see Chapter 4 for more information about specifying Rating Request parameters).

If “Use Stage Analysis? = Yes,” the program reads the stresses on beams and slabs directly from the section cut results. The program assumes that the effects of the staging of loads applied to non-composite versus composite section as well as the concrete slab material time dependent properties were captured using the Nonlinear Staged Construction load case available in CSiBridge. In case any of the user defined combos for demands sets γ_{DC}DC or γ_{DW}DW contain multiple StepTypes, the StepTypes for the DC and DW demands are selected to match the StepType of the LLIM case that is being processed. In other words, the rating factor is calculated for DC, DW and LLIM StepType = Max and then again for DC, DW and LLIM StepType = Min. The StepType that produces the smallest rating factor is reported in the output table.

If “Use Stage Analysis? = No,” the program decomposes load cases present in the DC demand set combo to two Bridge Design Action categories: non-composite and composite long term. All load cases present in the DW demand set combo are assigned to the composite long-term category and all load cases present in the LLIM demand set combo are assigned to the composite short-term category.

The program uses the load case Bridge Design Action parameter to assign the load cases present in the DC demand set combo to the appropriate categories. A default Bridge Design Action parameter is assigned to a load case based on its Design Load Type. However, the parameter can be overwritten: click the **Analysis > Load Cases > {Type} > New** command to display the Load Case Data – {Type} form; click the **Design** button next to the Load case type drop down list; under the heading *Bridge Design Action*, select the User Defined option and select a value from the list. The assigned Bridge Designed Action values are handled by the program in the following manner:

Table 5-3 Bridge Design Action

Bridge Design Action Value	Bridge Design Action Category Used in

Specified By the User	the Design Algorithm
Non-Composite	Non-Composite
Long-Term Composite	Long-Term Composite
Short-Term Composite	Short-Term Composite
Staged	Non-Composite
Other	Non-Composite

In case any of the user defined combos for demands sets γ_{DC}DC or γ_{DW}DW contain multiple StepTypes, the M3 demands from the Max and Min StepTypes are consolidated into one ABS StepType. This is completed by selecting the maximum absolute from the two StepType values while preserving the sign.

5.3.1.1 Demand Flange Stresses f_{bu} and f_f

Evaluation of the flange stress, f_{bu}, calculated without consideration of the flange lateral bending is dependent on setting the Rating Request parameter "Use Stage Analysis?"

If the "Use Stage Analysis? = No," then

$$f_{\text{buDC}} = \frac{M_{\text{DCNonComp}}}{s_{\text{Steel}}} + \frac{M_{\text{DCComp}}}{s_{\text{LTC}}}$$

$$f_{bu\text{DW}} = \frac{M_{\text{DW}}}{s_{\text{LTC}}}$$

$$f_{bu\text{LLIM}} = \frac{M_{\text{LLIM}}}{s_{\text{STC}}}$$

where $M_{\text{DCNonComp}}$ is the DC demand moment on the non-composite section, M_{DCComp} is the DC demand moment on the long-term composite section, M_{DW} is the DW demand moment on the long-term composite section, and M_{LLIM} is the LLIM demand moment on the short-term composite section.

The short-term section modulus for positive moment S_{STC} is calculated by transforming the concrete deck using the steel-to-concrete modular ratio. The long-term section modulus for positive moment S_{LTC} is using a modular ratio factored by n, where n is specified in the rating parameter “Modular ratio long term multiplier.” The effect of compression reinforcement is ignored. For negative moment, the concrete deck is assumed to be cracked and is not included in the section modulus calculations, while tension reinforcement is accounted for.

If “Use Stage Analysis? = Yes,” then the f_{bu} stresses on each flange are read directly from the section cut results. The program assumes that the effects of the staging of loads applied to non-composite versus composite sections as well as the concrete slab material time dependent properties were captured using the Nonlinear Staged Construction load case available in CSiBridge.

In the Strength Rating Request the program verifies the sign of the stress in the composite slab and if stress is positive (tension), the program assumes that the entire section cut demand moment is carried by the steel section only. This is to reflect the fact that the concrete in the composite slab is cracked and does not contribute to the resistance of the section.

Flange stress f_f used in the Service Rating Request is evaluated in the same manner as stress f_{bu}, with one exception. When the Design Parameter “Does concrete slab resist tension?” in the Steel Composite Service rating request is set to “Yes,” the program uses section properties based on a transformed section, assuming the concrete slab to be fully effective in both tension and compression.

5.3.1.2 Demand Flange Lateral Bending Stress f_l

The f_l stress on each flange is read directly from the section cut results. The flange lateral bending stress f_l is evaluated only when all of the following conditions are met:

- “Steel Girders” has been selected for the deck section type (**Components** > **Superstructure Item** > **Deck Sections** command) and the **Girder Modeling In Area Object Models** – Model Girders Using Area Objects option is set to “Yes” on the Define Bridge Section Data – Steel Girder form.

- The bridge object is modeled using Area Objects. This option can be set using the **Bridge > Update** command to display the Update Bridge Structural Model form; then select the Update as Area Object Model option.

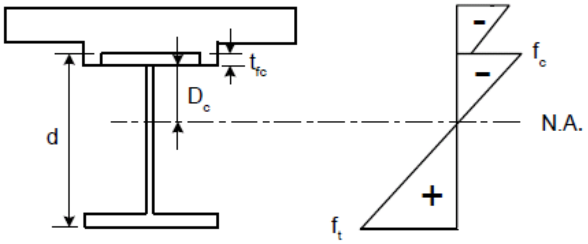
- The Live Load Distribution to Girders method has been set to “Use Directly Forces from CSiBridge” on the Bridge Rating Request – Superstructure – {Code} form, which displays when the **Design/Rating > Load Rating > Rating Requests** command is used (see Chapter 3 for more information about Live Load Distribution).

In all other cases, the flange lateral bending stress is set to zero.

5.3.1.3 Depth of the Web in Compression

For composite sections in positive flexure the depth of web in compression is computed using the following equation:

$$D_c = \left(\frac{-f_c}{|f|_c + f_t} \right) d - t_{fc} \geq 0 \qquad \text{(D6.3.1-1)}$$



where

f_c = Sum of the compression-flange stresses caused by the different loads acting on their respective sections, i.e., DC1, the permanent load acting on the non-composite section; DC2, the permanent load acting on the long-term composite section; DW, the wearing surface load; and LL+IM. f_c is taken as negative when the stress is in compression. Flange lateral bending is disregarded in this calculation.

f_t = The sum of the tension-flange stresses caused by the different loads. Flange lateral bending is disregarded in this calculation.

For composite sections in negative flexure, D_c is computed for the section consisting of the steel girder plus the longitudinal reinforcement, with the exception of the following. For composite sections in negative flexure at the Service Design Check Request where the concrete deck is considered effective in tension for computing flexural stresses on the composite section (Design Parameter “Does concrete slab resist tension?” = Yes), D_c is computed from Eq. D6.3.1-1. For this case, the stresses f_c and f_t are switched, the signs shown in the stress diagram are reversed, t_{fc} is the thickness of the bottom flange, and D_c instead extends from the neutral axis down to the top of the bottom flange.

5.3.2 Moment Gradient Modifier C_b

When the design request parameter ‘Method for determining moment gradient factor C$_b$‘ is set to ‘Program Determined’, then for each demand set the stresses defined in AASHTO LRFD section 6.10.8.2.3 f_{mid}, f_0,f_1 and f_2 at the unbraced segment are determined by interpolation of demands at nearest section cuts. The designer should be aware that live load moments at neighboring section cuts within the unbraced segment are not necessarily controlled by the same load pattern and as a result the moment gradient calculation may be impacted. The moment gradient modifier C_b is then calculated as:

- For unbraced cantilevers and for members where

  $f_{mid}/f_2 > 1$ or $f_2 = 0$

  $$C_b = 1.0 \qquad (6.10.8.2.3\text{-}6)$$

- For all other cases:

  $$C_b = 1.75 - 1.05\left(\frac{f_1}{f_2}\right) + 0.3\left(\frac{f_1}{f_2}\right)^2 \leq 2.3 \qquad (6.10.8.2.3\text{-}7)$$

5.3.3 Non-Composite Sections

5.3.3.1 Demand Flange Stresses f_{bu} and f_f

The stresses are calculated based on the assumption that only the steel beam resists moments applied to the entire girder (= steel beam plus tributary area of slab).

5.3.3.2 Demand Flange Lateral Bending Stress f_l

The flange lateral bending stress f_l is set to zero.

5.3.3.3 Depth of the Web in Compression

D_c is computed based on the location of the steel beam neutral axis.

5.4 Strength Rating Request

The Strength Rating Request calculates at every section cut positive flexural capacity, negative flexural capacity, and shear capacity. It then calculates the rating factor per algorithm described in Section 5.1 of this manual.

5.4.1 Flexure

5.4.1.1 Positive Flexure – Compact

The nominal flexural resistance of the section is evaluated as follows:

If $D_p \leq 0.1\, D_t$, then $M_n = M_p$, otherwise

$$M_n = M_p\left(1.07 - 0.7\frac{D_p}{D_t}\right) \qquad (6.10.7.1.2\text{-}2)$$

In a continuous span the nominal flexural resistance of the section is determined as

$$M_n \leq 1.3 R_h M_y$$

where R_h is a hybrid factor for the section in positive flexure.

The rating factor is evaluated as

$$RF = \frac{\varphi_c \varphi_s \varphi_{\text{flex}} M_n - \frac{1}{3} S_{xt} \left| f_{l\text{DC}} + f_{l\text{DW}} \right| - M_{u\text{DC}} - M_{u\text{DW}}}{M_{u\text{LLIM}} + \frac{1}{3} S_{xt} \left| f_{l\text{LLIM}} \right|}$$

5.4.1.2 Positive Flexure – Non-Compact

Nominal flexural resistance of the top compression flange is taken as:

$F_{nc} = R_b R_h F_{yc}$ (6.10.7.2.2-1)

Nominal flexural resistance of the bottom tension flange is taken as:

$F_{nt} = R_h F_{yt}$ (6.10.7.2.2-1)

The rating factor is evaluated as

$$RF_c = \frac{\varphi_c \varphi_s \varphi_{\text{flex}} F_{nc} - f_{bu\text{DC}} - f_{bu\text{DW}}}{f_{bu\text{LLIM}}}$$

$$RF_c = \frac{\varphi_c \varphi_s \varphi_{\text{flex}} F_{nt} - \frac{1}{3}\left| f_{t\text{DC}} + f_{l\text{DW}} \right| - f_{bu\text{DC}} - f_{bu\text{DW}}}{f_{bu\text{LLIM}} + \frac{1}{3}\left| f_{l\text{LLIM}} \right|}$$

$$RF_{\text{deck}} = \frac{\varphi_c \varphi_s 0.6 f'_c - f_{\text{deckDW}}}{f_{\text{deckLLIM}}}$$

$$RF = \min\left(RF_c, RF_t, RF_{\text{deck}}\right)$$

5.4.1.3 Negative Flexure in Accordance with Article 6.10.8

The local buckling resistance of the compression flange $F_{nc(\text{FLB})}$ as specified in Article 6.10.8.2.2 is taken as:

If $\lambda_f \leq \lambda_{pf}$, then $F_{nc} = R_b R_h F_{yc}$. (6.10.8.2.2-1)

Otherwise

$$F_{nc} = \left[1 - \left(1 - \frac{F_{yr}}{R_h F_{yc}}\right)\left(\frac{\lambda_f - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right] R_b R_h F_{yc} \qquad (6.10.8.2.2\text{-}2)$$

in which

$$\lambda_f = \frac{b_{fc}}{2t_{fc}} \qquad (6.10.8.2.2\text{-}3)$$

$$\lambda_{pf} = 0.38\sqrt{\frac{E}{F_{yc}}} \qquad (6.10.8.2.2\text{-}4)$$

$$\lambda_{rf} = 0.56\sqrt{\frac{E}{F_{yr}}} \qquad (6.10.8.2.2\text{-}5)$$

F_{yr} = compression-flange stress at the onset of nominal yielding within the cross-section, including residual stress effects, but not including compression-flange lateral bending, taken as the smaller of $0.7F_{yc}$ and F_{yw}, but not less than $0.5F_{yc}$.

The lateral torsional buckling resistance of the compression flange $F_{nc(\mathrm{LTB})}$ as specified in Article (6.10.8.2.3) is taken as follows:

If $L_b \le L_p$, then $F_{nc} = R_bR_hF_{yc}$. (6.10.8.2.3-1)

If $L_p < L_b \le L_r$, then

$$F_{nc} = C_b\left[1-\left(1-\frac{F_{yr}}{R_hF_{yc}}\right)\left(\frac{L_b-L_p}{L_r-L_p}\right)\right]R_bR_hF_{yc} \le R_bR_hF_{yc}. \qquad (6.10.8.2.3\text{-}2)$$

If $L_b > L_r$, then $F_{nc} = F_{cr} \le R_bR_hF_{yc}$ (6.10.8.2.3-3)

in which

$$L_b = \text{unbraced length,} \quad L_p = 1.0r_t\sqrt{\frac{E}{F_{yc}}}, \quad L_r = \pi r_t\sqrt{\frac{E}{F_{yr}}}$$

C_b = moment gradient modifier

$$F_{cr} = \frac{C_bR_b\pi^2E}{\left(\frac{L_b}{r_t}\right)^2} \qquad (6.10.8.2.3\text{-}8)$$

$$r_t = \frac{b_{fc}}{\sqrt{12\left(1+\frac{1}{3}\frac{D_ct_w}{b_{fc}t_{fc}}\right)}}. \qquad (6.10.8.2.3\text{-}9)$$

The nominal flexural resistance of the bottom compression flange is taken as the smaller of the local buckling resistance and the lateral torsional buckling resistance:

$$F_{nc} = \min\left[F_{nc(\mathrm{FLB})}, F_{nc(\mathrm{LTB})}\right]$$

The nominal flexural resistance of the top tension flange is taken as:

$$F_{nt} = R_h F_{yf}. \tag{6.10.8.1.3-1}$$

The demand over capacity ratio is evaluated as

$$RF_c = \frac{\varphi_c \varphi_s \varphi_{\mathrm{flex}} F_{nc} - \frac{1}{3} S_{xt} \left| f_{l\mathrm{DC}} + f_{l\mathrm{DW}} \right| - f_{bu\mathrm{DC}} - f_{bu\mathrm{DW}}}{f_{bu\mathrm{LLIM}} + \frac{1}{3} \left| f_{l\mathrm{LLIM}} \right|}$$

$$RF_t = \frac{\varphi_c \varphi_s \varphi_{\mathrm{flex}} F_{nt} - f_{bu\mathrm{DC}} - f_{bu\mathrm{DW}}}{f_{bu\mathrm{LLIM}}}$$

$$RF = \min\left(RF_c, RF_t\right)$$

5.4.1.4 Negative Flexure in Accordance with Appendix A6

Sections that satisfy the following requirement qualify as compact web sections:

$$\frac{2D_{cp}}{t_w} \le \lambda_{pw\left(D_{cp}\right)} \tag{A6.2.1-2}$$

where

$$\lambda_{pw\left(D_{cp}\right)} = \frac{\sqrt{\frac{E}{F_{yc}}}}{\left(0.54 \frac{M_p}{R_h M_y} - 0.09\right)^2} \le \left(\frac{D_{cp}}{D_c}\right) \tag{A6.2.1-2}$$

$$\lambda_{rw} = 5.7 \sqrt{\frac{E}{F_{yc}}} \tag{A6.2.1-3}$$

D_c = depth of the web in compression in the elastic range

D_{cp} = depth of the web in compression at the plastic moment

Then web plastification factors are determined as

$$R_{pc} = \frac{M_p}{M_{yc}} \tag{A6.2.1-4}$$

$$R_{pt} = \frac{M_p}{M_{yt}} \tag{A6.2.1-5}$$

Sections that do not satisfy the requirement for compact web sections, but for which the web slenderness satisfies the following requirement:

$$\lambda_w < \lambda_{rw} \tag{A6.2.2-1}$$

where

$$\lambda_w = \frac{2D_c}{t_w} \tag{A6.2.2-2}$$

$$\lambda_{rw} = 5.7\sqrt{\frac{E}{F_{yc}}} \tag{A6.2.2-3}$$

The web plastification factors are taken as:

$$R_{pc} = \left[1 - \left(1 - \frac{R_h M_{yc}}{M_p}\right)\left(\frac{\lambda_w - \lambda_{pw(D_c)}}{\lambda_{tw} - \lambda_{pw(D_c)}}\right)\right]\frac{M_p}{M_{yc}} \le \frac{M_p}{M_{yc}} \tag{A6.2.2-4}$$

$$R_{pt} = \left[1 - \left(1 - \frac{R_h M_{yt}}{M_p}\right)\left(\frac{\lambda_w - \lambda_{pw(D_c)}}{\lambda_{rw} - \lambda_{pw(D_c)}}\right)\right]\frac{M_p}{M_{yt}} \le \frac{M_p}{M_{yt}} \tag{A6.2.2-5}$$

where

$$\lambda_{pw(D_c)} = \lambda_{pw(D_c p)}\left(\frac{D_c}{D_{cp}}\right) \le \lambda_{rw}. \tag{A6.2.2-6}$$

The local buckling resistance of the compression flange M_{ncFLB} as specified in Article A6.3.2 is taken as:

- If $\lambda_f \le \lambda_{pf}$, then $M_{nc} = R_{pc} M_{yc}$. (A6.3.2-1)

Otherwise $M_{nc} = \left[1 - \left(1 - \frac{F_{yr} S_{xc}}{R_{pc} M_{yc}}\right)\left(\frac{\lambda_f - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}}\right)\right] R_{pc} M_{yc}$ (A6.3.2-2)

in which

$$\lambda_f = \frac{b_{fc}}{2t_{fc}} \qquad \text{(A6.3.2-3)}$$

$$\lambda_{pf} = 0.38\sqrt{\frac{E}{F_{yc}}} \qquad \text{(A6.3.2-4)}$$

$$\lambda_{rf} = 0.95\sqrt{\frac{Ek_c}{F_{yr}}}. \qquad \text{(A6.3.2-5)}$$

For built-up sections, $k_c = \frac{4}{\sqrt{\frac{D}{t_w}}}$. (A6.3.2-6)

For rolled shapes (eFramePropType =SECTION_I as defined in API function SapObject.SapModel.PropFrame.GetNameList; PropType argument)

$k_c = 0.76$.

The lateral torsional buckling resistance of the compression flange $M_{nc\mathrm{LTB}}$ as specified in Article A6.3.3 is taken as:

- If $L_b \geq L_p$, then $M_{nc} = R_{pc} M_{yc}$. (A6.3.3-1)
- If $L_p < L_b \leq L_r$, then

$$M_{nc} = C_b\left[1 - \left(1 - \frac{F_{yr} S_{xc}}{R_{pc} M_{yc}}\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] R_{pc} M_{yc} \leq R_{pc} M_{yc}. \qquad \text{(A6.3.3-2)}$$

- If $L_b > L_r$, then $M_{nc} = F_{cr} S_{xc} \leq R_{pc} M_{yc}$. (A6.3.3-3)

in which

$L_b =$ unbraced length,

$$L_p = 1.0 r_t \sqrt{\frac{E}{F_{yc}}} \qquad \text{(A6.3.3-4)}$$

$$L_r = 1.95 r_t \frac{E}{F_{yr}} \sqrt{\frac{J}{S_{xc} h}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{F_{yr}}{E} \frac{S_{xc} h}{J} \right)^2}} \qquad \text{(A6.3.3-5)}$$

C_b = moment gradient modifier

$$F_{cr} = \frac{C_b \pi^2 E}{\left(L_b / r_t \right)^2} \sqrt{1 + 0.078 \frac{J}{S_{xc} h} \left(L_b / r_t \right)^2} \qquad \text{(A6.3.3-8)}$$

$$J = \frac{D t_w^3}{3} + \frac{b_{fc} t_{ft}^3}{3} \left(1 - 0.63 \frac{t_{fc}}{b_{fc}} \right) + \frac{b_{ft} t_{ft}^3}{3} \left(1 - 0.63 \frac{t_{ft}}{b_{ft}} \right) \qquad \text{(A6.3.3-9)}$$

$$r_t = \frac{b_{fc}}{\sqrt{12 \left(1 + \frac{1}{3} \frac{D_c t_w}{b_{fc} t_{fc}} \right)}} \qquad \text{(A6.3.3-10)}$$

The nominal flexural resistance of the bottom compression flange is taken as the smaller of the local buckling resistance and the lateral torsional buckling resistance:

$$M_{nc} = \min\left[M_{nc(\text{FLB})}, M_{nc(\text{LTB})} \right].$$

The nominal flexural resistance of the top tension flange is taken as:

$$M_{nt} = R_{pt} M_{yt}. \qquad \text{(A6.1.4-1)}$$

The rating factor is evaluated as:

$$RF_c = \frac{\varphi_c \varphi_s \varphi_{\text{flex}} M_{nc} - \frac{1}{3} S_{xc} \left| f_{l\text{DC}} + f_{l\text{DW}} \right| - M_{u\text{DC}} - M_{u\text{DW}}}{M_{u\text{LLIM}} + \frac{1}{3} S_{xc} \left| f_{l\text{LLIM}} \right|}$$

$$RF_t = \frac{\varphi_c \varphi_s \varphi_{\text{flex}} M_{nt} - M_{u\text{DC}} - M_{u\text{DW}}}{M_{u\text{LLIM}}}$$

$$RF = \min\left(RF_c, RF_t \right).$$

5.4.2 Shear

When processing the Rating Request from the Design/Rating module, the program assumes that there are no vertical stiffeners present and classifies all web panels as unstiffened. If the shear capacity calculated based on this classification is not sufficient to resist the demand specified in the Rating Request, the program recommends minimum stiffener spacing to achieve a Demand over Capacity ratio equal to 1. The recommended stiffener spacing is reported in the result table under the column heading d0req.

In the Optimization form (**Design/Rating** > **Load Rating** > **Optimize** command), the user can specify stiffeners locations and the program recalculates the shear resistance. In that case the program classifies the web panels as interior or exterior and stiffened or unstiffened based on criteria specified in section 6.10.9.1 of the code. It should be noted that stiffeners are not modeled in the Bridge Object and therefore adding/modifying stiffeners does not affect the magnitude of the demands.

5.4.2.1 Nominal Resistance of Unstiffened Webs

The nominal shear resistance of unstiffened webs is taken as:

$$V_n = CV_p \qquad (6.10.9.2\text{-}1)$$

in which

$$V_p = 0.58 F_{yw} D t_w \qquad (6.10.9.2\text{-}2)$$

C = the ratio of the shear-buckling resistance to the shear yield strength that is determined as follows:

$$\text{If } \frac{D}{t_w} \le 1.12\sqrt{\frac{Ek}{F_{yw}}}, \text{ then } C = 1.0. \qquad (6.10.9.3.2\text{-}4)$$

$$\text{If } 1.12\sqrt{\frac{Ek}{F_{yw}}} < \frac{D}{t_w} \le 1.40\sqrt{\frac{Ek}{F_{yw}}}, \text{ then } C = \frac{1.12}{\frac{D}{t_w}}\sqrt{\frac{Ek}{F_{yw}}}. \qquad (6.10.9.3.2\text{-}5)$$

$$\text{If } \frac{D}{t_w} > 1.40\sqrt{\frac{Ek}{F_{yw}}}, \text{ then } C = \frac{1.57}{\left(\frac{D}{t_w}\right)^2}\left(\frac{Ek}{F_{yw}}\right), \qquad (6.10.9.3.2\text{-}6)$$

$$\text{in which } k = 5 + \frac{5}{\left(\frac{d_c}{D}\right)^2}. \qquad (6.10.9.3.2\text{-}7)$$

5.4.2.2 Nominal Resistance of Stiffened Interior Web Panels

The nominal shear resistance of an interior web panel, with the section at the section cut proportioned such that

$$\frac{2Dt_w}{\left(b_{fc}t_{fc} + b_{ft}t_{ft}\right)} \leq 2.5, \qquad (6.10.9.3.2\text{-}1)$$

is taken as

$$V_n = V_p\left[C + \frac{0.87(1-C)}{\sqrt{1+\left(\frac{d_o}{D}\right)^2}}\right] \qquad (6.10.9.3.2\text{-}2)$$

$$\text{in which } V_p = 0.58F_{yw}Dt_w \qquad (6.10.9.3.2\text{-}3)$$

where

d_o = transverse stiffener spacing.

Otherwise, the nominal shear resistance is taken as follows:

$$V_n = V_p\left[C + \frac{0.87(1-C)}{\left(\sqrt{1+\left(\frac{d_o}{D}\right)^2} + \frac{d_o}{D}\right)}\right] \qquad (6.10.9.3.2\text{-}8)$$

5.4.2.3 Nominal Resistance of End Panels

The nominal shear resistance of a web end panel is taken as:

$$V_n = V_{cr} = CV_p \qquad (6.10.9.3.3\text{-}1)$$

in which

$$V_p = 0.58 F_{yw} D t_w. \qquad (6.10.9.3.3\text{-}2)$$

5.4.2.4 Shear Rating Factor

The rating factor is evaluated as

$$RF = \frac{\varphi_c \varphi_s \varphi_{\text{shear}} V_n - V_{u\text{DC}} - V_{u\text{DW}}}{V_{u\text{LLIM}}}$$

5.5 Service Rating Request

The Services Rating Request Check calculates at every section cut stresses f_f at the top steel flange and bottom steel flange, and for composite section it calculates the stress f_{deck} at the top of the fiber of the concrete deck. The capacities are based on section 6.10.4.2.2 of the code.

The flange stresses are derived in the same way as the f_{bu} stress demands (see section 5.3.1.1 and 5.3.2.1 of this manual). For composite sections the user has an option to specify if the concrete slab resists tension by setting the rating request parameter “Does concrete slab resist tension?” It is the responsibility of the user to verify if the slab qualifies to resist tension in accordance with section 6.10.4.2.1 of the code.

5.5.1 Composite Sections

The rating factor for the top steel flange of composite sections is as follows:

$$RF_{\text{top}} = \frac{\varphi_c \varphi_s 0.95 R_h F_{yf} - f_{bu\text{DC}} - f_{bu\text{DW}}}{f_{bu\text{LLIM}}}. \qquad (6.10.4.2.2\text{-}1)$$

The rating factor for the bottom steel flange of composite sections is as follows:

$$RF_{\text{bot}} = \frac{\varphi_c \varphi_s 0.95 R_h F_{yf} - \frac{1}{2}\left| f_{l\text{DC}} + f_{l\text{DW}} \right| f_{bu\text{DC}} - f_{bu\text{DW}}}{f_{bu\text{LLIM}} + \frac{1}{2}\left| f_{lLLIM} \right|}. \qquad (6.10.4.2.2\text{-}2)$$

The rating factor for the deck of compact composite sections in positive flexure used in shored construction is a follows:

$$RF_{deck} = \frac{\varphi_c \varphi_s 0.6 f'_c - f_{\text{deckDW}}}{f_{\text{deckLLIM}}}. \qquad (6.10.4.2.2)$$

The rating factor for the bend–buckling resistance of webs (not evaluated for composite sections in positive flexure) is as follows:

$$RF_{crw} = \frac{\varphi_c \varphi_s F_{crw} - f_{bu\text{DC}} - f_{bu\text{DW}}}{f_{bu\text{LLIM}}} \qquad (6.10.4.2.2\text{-}4)$$

where

f_c = Compression-flange stress at the section under consideration due to demand loads, calculated without consideration of flange lateral bending.

F_{crw} = Nominal bend-buckling resistance for webs without longitudinal stiffeners, determined as specified in Article 6.10.1.9.

$$F_{crw} = \frac{0.9Ek}{\left(\frac{D}{t_w}\right)^2} \qquad (6.10.1.9.1\text{-}1)$$

but not to exceed the smaller of $R_h F_{yc}$ and $F_{yw}/0.7$. In which

k = Bend-buckling coefficient

$$k = \frac{9}{\left(D_c/D\right)^2} \qquad (6.10.1.9.1\text{-}2)$$

where D_c= depth of the web in compression in the elastic range, determined as specified in Article D6.3.1 of the code.

When both edges of the web are in compression, k is taken as 7.2.

The controlling rating factor is evaluated as:

$$RF = \min\left(RF_{\text{top}}, RF_{\text{bot}}, RF_{\text{deck}}, RF_{\text{crw}}\right)$$

5.5.2 Non-Composite Sections

For both steel flanges of non-composite sections:

$$RF = \frac{\varphi_c \varphi_s 0.8 R_h F_{yf} - \frac{1}{2}\left| f_{l\mathrm{DC}} + f_{l\mathrm{DW}} \right| - f_{bu\mathrm{DC}} - f_{bu\mathrm{DW}}}{f_{bu\mathrm{LLIM}} + \frac{1}{2}\left| f_{l\mathrm{LLIM}} \right|} \qquad (6.10.4.2.2\text{-}3)$$

5.6 Section Optimization

After at least one Steel Rating Request has been successfully processed, CSiBridge enables the user to open a Steel Section Optimization module. The Optimization module allows interactive modification of steel plate sizes and definition of vertical stiffeners along each girder and span. It recalculates resistance “on the fly” based on the modified section without the need to unlock the model and rerun the analysis. It should be noted that in the optimization process the demands are not recalculated and are based on the current CSiBridge analysis results.

The Optimization form allows simultaneous display of three versions of section sizes and associated resistance results. The section plate size versions are “As Analyzed,” “As Designed,” and “Current.” The section plots use distinct colors for each version – black for As Analyzed, blue for As Designed, and red for Current. When the Optimization form is initially opened, all three versions are identical and equal to “As Analyzed.”

Two graphs are available to display various forces, moments, stresses, and ratios for the As Analyzed or As Designed versions. The values plotted can be controlled by clicking the **Select Series to Plot** button. The As Analyzed series is plotted as solid lines and the As Designed series as dashed lines.

To modify steel plate sizes or vertical stiffeners, a new form can be displayed by clicking on the **Modify Section** button. After the section modification has been completed, the Current version is shown in red in the elevation and cross-section views. After the resistance has been recalculated successfully by clicking the **Recalculate Resistance** button, the Current version is designated As Designed and displayed in blue.

After the section optimization has been completed, the As Designed plate sizes and materials can be applied to the analysis bridge object by clicking the **OK** button. The button opens a new form that can be used to Unlock the existing model (in that case all analysis results will be deleted) or save the file under a new name (**New File** button). Clicking the **Exit** button does not apply the new plate sizes to the bridge object and keeps the model locked. The As Designed version of the plate sizes will be available the next time the form is opened, and the Current version is discarded.

5.7 PennDOT Amendments for DM-4

When setting the bridge rating preferences for the AASHTO Rating 2010 code, and also using the Rating Resistance Code “AASHTO LRFD 2014”, an option called “Rating Resistance Code Amendments” is available which can be set to “None” or “PennDOT”. This is done using command Design/Rating > Load Rating > Preferences.

With this option is set to “PennDOT”, the following change is made to the rating procedure to account for the requirements of the Pennsylvania Department of Transportation (PennDOT) Design Manual, Part 4, April 2015 Edition (DM-4):

> When live-load distribution factors (LLDF) are used, these are calculated taking into account the provisions of DM-4 Section 4.6.2.2.

The DM-4 Section 6.10.1.5 requirement to ignore haunches when computing flexural stiffness and resistance of beams while taking into account the haunch dead weight can be approximately satisfied by specifying haunch thickness in the bridge-section definition equal to the maximum flange thickness. The weight of the remaining haunch can be applied as a superimposed line load on top the girders. If you choose instead to include the full haunch thickness in the model, the difference in results tends to be small unless the haunch is deep.

Prior to running the load rating, the analysis should be include the appropriate PennDOT vehicles as needed for live load. A PennDOT vehicle library is provided in addition to the regular AASHTO vehicles. Use the command Loads > Vehicles, and click the lower right arrow icon to show the Define Vehicles form. Then use the Import button to locate the vehicles under Unites States > PennDOT. Once imported, these vehicles can be modified, if necessary.

Appropriate load combinations should be created prior to running the superstructure design. Use the command Design Rating > Load Combinations > Add Defaults. Select “Bridge Design”, and set “Amendment” to “PennDOT–Steel Girder”. See section 2.2.3 “AASHTO LRFD Code with PennDOT Amendments” in the *CSiBridge 2016 Bridge Superstructure Design AASHTO 2014* manual for more information.