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Integrated Solution for
Structural Analysis and Design

Steel Frame Design Manual

AISC 360-05 / IBC 2006





**Steel Frame
Design Manual**
AISC 360-05 / IBC 2006
For SAP2000®

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Chapter 1

Introduction

The design/check of steel frames is seamlessly integrated within the program. Initiation of the design process, along with control of various design parameters, is accomplished using the Design menu. Automated design at the object level is available for any one of a number of user-selected design codes, as long as the structures have first been modeled and analyzed by the program. Model and analysis data, such as material properties and member forces, are recovered directly from the model database, and are used in the design process in accordance with the user defined or default design settings. As with all design applications, the user should carefully review all of the user options and default settings to ensure that the design process is consistent with the user's expectations. The AISC 360-05/IBC 2006 steel frame design options include the use of the Direct Analysis Method. The software is well suited to make use of the Direct Analysis Method because it can capture the second-order P-Delta and P- δ effects, provided the user specifies that a nonlinear P-Delta analysis be performed.

It should be noted that two design processes are available in CSiBridge: superstructure design (on the Design/Rating tab) and design of the individual elements comprising the structure (the **Advanced > Frame Design** commands). This manual addresses the second design process.

Chapter 2 addresses prerequisites related to modeling and analysis for a successful design in accordance with "AISC 360-05/IBC 2006." Chapter 3 pro-

vides detailed descriptions of the specific requirements as implemented in "AISC 360-05/IBC 2006." Chapter 4 provides detailed descriptions of the specific requirements for seismic loading as required by the specification in AN-SI/AISC 341-05 code. The appendices provide details on various topics referenced in this manual. The user also should review the *AISC Direct Analysis Method Practical Guide*.

1.1 Load Combinations and Notional Loads

The design is based on a set of user-specified loading combinations. However, the program provides default load combinations for each supported design code. If the default load combinations are acceptable, no definition of additional load combinations is required. The Direct Analysis Method requires that a notional load, $N = 0.002Y_i$, where Y_i is the gravity load acting at level i , be applied to account for the destabilizing effects associated with the initial imperfections and other conditions that may induce sway not explicitly modeled in the structure. The user must be aware that notional loads must be defined and assigned by the user. Currently, the software creates design combinations that include notional loads and gravity loads only. If the user needs notional loads that include combinations containing lateral loads, the user must define such combinations manually. The automation of combinations, including notional loads, is currently limited to gravity loads only. Design load combinations of notional loads acting together with lateral loads currently are *NOT* automated by the software.

1.2 Stress Check

Steel frame design/check consists of calculating the flexural, axial, and shear forces or stresses at several locations along the length of a member, and then comparing those calculated values with acceptable limits. That comparison produces a demand/capacity ratio, which typically should not exceed a value of one if code requirements are to be satisfied. The program follows the same review procedures whether it is checking a user-specified shape or a shape selected by the program from a predefined list. The program also checks the requirements for the beam-column capacity ratio, checks the capacity of the

panel zone, and calculates the doubler plate and continuity plate thickness, if needed. The program does not do the connection design. However, it calculates the design basis forces for connection design.

Program output can be presented graphically on the model, in tables for both input and output data, or in calculation sheets prepared for each member. For each presentation method, the output is in a format that allows the engineer to quickly study the stress conditions that exist in the structure, and in the event the member is not adequate, aid the engineer in taking appropriate remedial measures, including altering the design member without re-running the entire analysis.

The program supports a wide range of steel frame design codes, including many national building codes. This manual is dedicated to the use of the menu option "AISC 36005/IBC 2006." This option covers the "ANSI/AISC 360-05 Specification for Structural Steel Buildings" (AISC 2005a, b), and the "ANSI/AISC 341-05 Seismic Provisions for Structural Steel Buildings Including Supplement No. 1" (AISC 2005c) codes.

The implementation covers loading and load combinations from "ASCE/SEI 705 Minimum Design Loads for Buildings and Other Structures" (ASCE 2005), and also special requirements from "IBC 2006 International Building Code" (IBC 2006). Both LRFD (Load and Resistance Factor Design) and ASD (Allowable Strength Design) codes are included in this implementation under the same "AISC 360-05/IBC 2006" code name. The LRFD and ASD are available as two options in the program's preferences feature. In both cases, the strengths are calculated in the nominal levels. The phi (LRFD) and Omega (ADS) factors are applied during calculation of demand/capacity ratios only. The design codes supported under "AISC 360-05/IBC 2006" are written in kip-inch units. All the associated equations and requirements have been implemented in the program in kip-in units. The program has been enabled with unit conversion capability. This allows the users to enjoy the flexibility of choosing any set of consistent units during creating and editing models, exporting and importing the model components, and reviewing the design results.

1.3 Direct Analysis Method vs. Effective Length Method

The Direct Analysis Method described in AISC 360-05/IBC 2006, Appendix 7, is substantially different from previous design methods supported by AISC. The user should be knowledgeable about the Stability Analysis and Design (Chapter C) requirements and the requirements pertaining to consideration of the geometric imperfections, stiffness reductions, and the P- Δ and P- δ effects. Several methods for consideration of the second-order effects are available to the users. Each of these are described in detail in a subsequent section (see User Options in this chapter) and in the Steel Frame Design Preferences, Appendix B of this manual. Alternatively, if the user desires to use a more traditional design method, the Effective Length method can be specified using the Design Preferences.

1.3.1 Effective Length Method

For structures exhibiting small second-order effects, the effective length method may be suitable. The effective length approach relies on two main assumptions, namely, that the structural response is elastic and that all columns buckle simultaneously. The effective length method also relies on a calibrated approach to account for the differences between the actual member response and the 2nd-order elastic analysis results. The calibration is necessary because the 2nd-order elastic analysis does not account for the effects of distributed yielding and geometric imperfections. Since the interaction equations used in the effective length approach rely on the calibration corresponding to a 2nd-order elastic analysis of an idealized structure, the results are not likely representative of the actual behavior of the structure. However, the results are generally conservative. In the AISC 360-05/IBC 2006 code, the effective length method is allowed provided the member demands are determined using a second-order analysis (either explicit or by amplified first-order analysis) and notional loads are included in all gravity load combinations. K-factors must be calculated to account for buckling (except for braced frames, or where $\Delta_2 / \Delta_1 < 1.0$, $K = 1.0$)

1.3.2 Direct Analysis Method

The Direct Analysis Method is expected to more accurately determine the internal forces of the structure, provided care is used in the selection of the appropriate methods used to determine the second-order effects, notional load effects and appropriate stiffness reduction factors as defined in AISC 2.2, App. 7.3(3). Additionally, the Direct Analysis Method does not use an effective length factor other than $k = 1.0$. The rationale behind the use of $k = 1.0$ is that proper consideration of the second-order effects ($P-\Delta$ and $P-\delta$), geometric imperfections (using notional loads) and inelastic effects (applying stiffness reductions) better accounts for the stability effects of a structure than the earlier Effective Length methods.

1.4 User Options

In addition to offering ASD and LRFD design, the Design Options menu provides seven analysis methods for design, as follows:

- General Second Order Elastic Analysis (AISC C2.2a)
- Second Order Analysis by Amplified First Order Analysis (AISC C2.1b)
- Limited First Order Elastic Analysis (AISC 2.2b, App. 7.3(1))
- Direct Analysis Method with General Second Order Analysis and Variable Factor Stiffness Reduction (AISC 2.2, App. 7.3(3))
- Direct Analysis Method with General Second Order Analysis and Fixed Factor Stiffness Reduction (AISC 2.2, App. 7.3(3))
- Direct Analysis Method with Amplified First Order Analysis and Variable Factor Stiffness Reduction (AISC 2.2, App. 7.3(3))
- Direct Analysis Method with Amplified First Order Analysis and Fixed Factor Stiffness Reduction (AISC 2.2, App. 7.3(3))

These options are explained in greater detail in Chapter 2. The first three options make use of the effective length approach to determine the effective length factors, K . The four options available for the Direct Design Method dif-

fer in the use of a variable or fixed stiffness reduction factor and the method used to capture the second-order effects. All four Direct Analysis Methods options use an effective length factor, $K = 1.0$.

1.5 Non-Automated Items in the AISC 360-05/IBC 2006 Steel Frame Design

Currently, the software does not automate the following:

- Notional loads combinations that include lateral wind and quake loads
- The validity of the analysis method. The user must verify the suitability of the specified analysis method used under the User Options described in the preceding sections. The AISC code requires, for instance, that the Direct Analysis Method be used when a ratio of the second order displacements to the first order displacements exceeds 1.5. This check currently must be performed by the user.
- P- Δ analysis. Since many different codes are supported by the software and not all require a P- Δ analysis, the user must specify that a P- Δ analysis be performed during the analysis phase so that the proper member forces are available for use in the design phase. See the *AISC Direct Analysis Method Practical Guide* for additional information.

Chapter 2 Design Algorithms

This chapter provides an overview of the basic assumptions, design preconditions, and some of the design parameters that affect the design of steel frames.

For referring to pertinent sections of the corresponding code, a unique prefix is assigned for each code.

- Reference to the ANSI/AISC 360-05 code is identified with the prefix "**AISC.**"
- Reference to the ANSI/AISC 341-05 code is identified with the prefix "**AISC SEISMIC**" or sometimes "**SEISMIC**" only.
- Reference to the ASCE/SEI 7-05 code is identified with the prefix "**ASCE.**"
- Reference to the IBC 2006 code is identified with the prefix "**IBC.**"

2.1 Check and Design Capability

The program has the ability to check adequacy of a section (shape) in accordance with the requirements of the selected design code. Also the program can automatically choose (i.e., design) the optimal (i.e., least weight) sections from a predefined list that satisfies the design requirements.

To check adequacy of a section, the program checks the demand/capacity ("D/C") ratios at a predefined number of stations for each design load combination. It calculates the envelope of the D/C ratios. It also checks the other requirements on a pass or fail basis. If the capacity ratio remains less than or equal to the D/C ratio limit, which is a number close to 1.0, and if the section passes all the special requirements, the section is considered to be adequate, else the section is considered to be failed. The D/C ratio limit is taken as 0.95 by default. However, this value can be overwritten in the Preferences (see Chapter 3).

To choose (design) the optional section from a predefined list, the program first orders the list of sections in increasing order of weight per unit length. Then it starts checking each section from the ordered list, starting with the one with least weight. The procedure of checking each section in this list is exactly the same as described in the preceding paragraph. The program will evaluate each section in the list until it finds the least weight section that passes the code checks. If no section in the list is acceptable, the program will use the heaviest section but flag it as being overstressed.

To check adequacy of an individual section, the user must assign the section using the **Assign** menu. In that case, both the analysis and design sections will be changed.

To choose the optimal section, the user must first define a list of steel sections, the *Auto Select* sections list. The user must next assign this list, in the same manner as any other section assignment, to the frame members to be optimized. The program will use the median section by weight when doing the initial analysis. Check the program Help for more information about defining and assigning Auto Select Section lists.

2.2 Design and Check Stations

For each design combination, steel frame members (beams, columns, and braces) are designed (optimized) or checked at a number of locations (stations) along the length of the object. The stations are located at equally spaced segments along the clear length of the object. By default, at least three stations will be located in a column or brace member, and the stations in a beam will be spaced at most 2 feet apart (0.5 m if the model has been created in metric

units). The user can overwrite the number of stations in an object before the analysis is run and refine the design along the length of a member by requesting more stations. Refer to the program Help for more information about specifying the number of stations in an object.

2.3 Demand/Capacity Ratios

Determination of the controlling demand/capacity (D/C) ratios for each steel frame member indicates the acceptability of the member for the given loading conditions. The steps for calculating the D/C ratios are as follows:

- The factored forces are calculated for axial, flexural, and shear at each defined station for each design combination. The bending moments are calculated about the principal axes. For I-Shape, Box, Channel, T-Shape, Double-Angle, Pipe, Circular, and Rectangular sections, the principal axes coincide with the geometric axes. For Single-Angle sections, the design considers the principal properties. For General sections, it is assumed that all section properties are given in terms of the principal directions.

For Single-Angle sections, the shear forces are calculated for directions along the geometric axes. For all other sections, the program calculates the shear forces along the geometric and principal axes.

- The nominal strengths are calculated for compression, tension, bending and shear based on the equations provided later in this manual. For flexure, the nominal strengths are calculated based on the principal axes of bending. For the I-Shape, Box, Channel, Circular, Pipe, T-Shape, Double-Angle and Rectangular sections, the principal axes coincide with their geometric axes. For the Angle sections, the principal axes are determined and all computations related to flexural stresses are based on that.

The nominal strength for shear is calculated along the geometric axes for all sections. For I-Shape, Box, Channel, T-Shape, Double-Angle, Pipe, Circular, and Rectangular sections, the principal axes coincide with their geometric axes. For Single-Angle sections, principal axes do not coincide with the geometric axes.

- Factored forces are compared to nominal strengths to determine D/C ratios. In either case, design codes typically require that the ratios not exceed a value of one. A capacity ratio greater than one indicates a member that has exceeded a limit state.

2.4 Design Load Combinations

The design load combinations are the various combinations of the prescribed load cases for which the structure needs to be checked. The program creates a number of default design load combinations for steel frame design. Users can add their own design combinations as well as modify or delete the program default design load combinations. An unlimited number of design load combinations can be specified.

To define a design load combination, simply specify one or more load cases, each with its own scale factor. The scale factors are applied to the forces and moments from the load cases to form the factored design forces and moments for each design load combination.

For normal loading conditions involving static dead load (DL), live load (LL), roof live load (RL), snow load (SL), wind load (WL), earthquake load (EL), notional load (NL), and dynamic response spectrum load (EL), the program has built-in default design combinations for the design code. These are based on the code recommendations.

The default design combinations assume all load cases declared as dead or live to be additive. However, each load case declared as wind, earthquake, or response spectrum cases, is assumed to be non-additive with other loads and produces multiple lateral combinations. Also static wind, earthquake and notional load responses produce separate design combinations with the sense (positive or negative) reversed. The notional load patterns are added to load combinations involving gravity loads only.

For other loading conditions involving moving load, time history, pattern live load, separate consideration of roof live load, snow load, and the like, the user must define the design load combinations in lieu of or in addition to the default design load combinations. If notional loads are to be combined with other load combinations involving wind or earthquake loads, the design load combina-

tions need to be defined in lieu of or in addition to the default design load combinations.

For multi-valued design combinations, such as those involving response spectrum, time history, moving loads and envelopes, where any correspondence between forces is lost, the program automatically produces sub-combinations using the maxima/minima values of the interacting forces. Separate combinations with negative factors for response spectrum load cases are not required because the program automatically takes the minima to be the negative of the maxima response when preparing the sub-combinations described previously.

The program allows live load reduction factors to be applied to the member forces of the reducible live load case on a member-by-member basis to reduce the contribution of the live load to the factored responses.

2.5 Second Order P-Delta Effects

The AISC 360-05/IBC 2006 steel frame design options include the use of the Direct Analysis Method. The software is well suited to make us of the Direct Analysis Method because each program can capture the second-order P- Δ and P- δ effects, provided the user specifies that a nonlinear P-Delta analysis be performed.

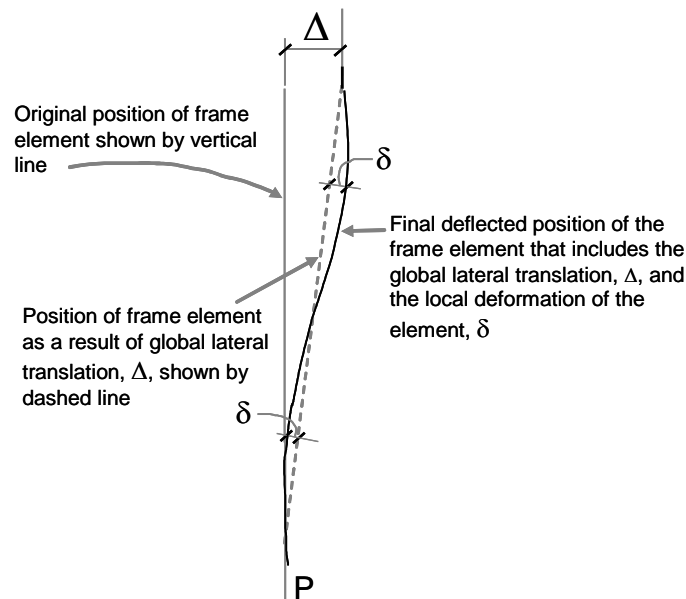


Figure 2-1 System sway and element order effects

For a detailed discussion of the program capabilities and limitations, see Appendix A.

2.6 Analysis Methods

The code requires that stability shall be provided for the structure as a whole and for each of the elements. Any method of analysis that considers the influence of second order effects of $P-\Delta$ and $P-\delta$, geometric imperfections, out-of-plumbness, and member stiffness reduction due to residual stresses are permitted by the code. The effects of geometric imperfection and out-of-plumbness generally are captured by the use of notional loads. The effect of axial, shear and flexural deformations and the effects of residual stresses on the member stiffness reduction has been considered in a specialized method called "Direct Analysis Method." This method can come in different incarnations (formats) according to the choice of the engineer as allowed in the code.

The program offers the user seven analysis options for design:

Direct Analysis Method

- General Second Order Elastic Analysis **with**
 - τ_b variable (user option 1, Default)
 - τ_b fixed (user option 2)
- Amplified First Order Elastic Analysis with
 - τ_b variable (user option 3)
 - τ_b fixed (user option 4)

Equivalent Length Method

- General Second Order Elastic Analysis (AISC C2.1a) (user option 5)
- Amplified First Order Elastic Analysis (AISC C2.1b) (user option 6)

Limited First-Order Analysis (AISC 2.2b, App. 7.3(1)) (user option 7)

A summary of all of the user options and requirements is provided in Table 2-1. The main difference between the various options concerns the use of the Direct Analysis Method or the Equivalent Length Method. Within each of the categories, the user can choose the method to calculate the second-order effects, namely, by a *General Second Order Analysis* or an *Amplified First-Order Analysis*. When the amplified first-order analysis is used, the force amplification factors, B_1 and B_2 (AISC C2.1b), are needed. The B_1 factor is calculated by the program; however, the B_2 factor is not. The user will need to provide this value using the overwrite options that are described in Appendix B.

When the user selects one of the options available under the Direct Analysis Method, the user must further choose how the stiffness reduction factors for EI and AE are to be considered. For options 1 and 3, Table 2-1, the stiffness reduction factors (τ_b) are variable because they are functions of the axial force in the members, while for methods 2 and 4, the stiffness reduction factors are fixed (0.8), and not a function of axial force. If the user desires, the stiffness reduction factors (τ_b) can be overwritten. When options 2 and 4 are used, a higher notional load coefficient (0.003) must be used compared to methods 1 and 3 for which the notional load coefficient is 0.002. Also, all the direct analysis methods (methods 1 through 4) allow use of K -factors for sway condition

(K_2) to be equal to 1, which is a drastic simplification over the other effective length method.

The AISC requirements to include notional loads are also summarized in Table 2-1. The notional load coefficients (AISC C2.2a, App. 7.3) are summarized as well. The program automates creation of notional load combinations for all gravity loads but does not automate the creation of notional load combinations that include lateral wind or seismic loads. Combinations for notional loads with lateral loads are required for the Direct Analysis Method when the $\Delta_{2nd}/\Delta_{1st}$ exceeds 1.5. Additionally, combinations for notional loads with lateral loads are required if the Limited First Order Analysis, option 7, is used.

The Limited First Order Analysis, option 7, does not include the secondary $P-\Delta$ and $P-\delta$ effects. This method has very limited applicability and might be appropriate only when the axial forces in the columns are very small compared to their Euler buckling capacities.

When using the LRFD provision, the actual load combinations are used for second order $P-\Delta$ effects. When using the ASD provision, the load combinations are first amplified by 1.6 before the $P-\Delta$ analysis and then the results are reduced by a factor of (1/1.6) (AISC 2.2a, App. 7.3).

Table 2-1 The Essentials and Limitations of the Design Analysis Methods

| Direct Analysis Method | | | |
|-------------------------------|-------------------------------------|-----------------------------|---|
| Option | Variable | Limitation or Applicability | Essentials of the Method |
| General Second Order Analysis | Variable Factor Stiffness Reduction | No limitation | 2nd Order Analysis Reduced stiffness $EI^* = 0.8\tau_b EI$ $EA^* = 0.8EA$ $\tau_b = \begin{cases} 1.0 & \text{for } \frac{\alpha P_r}{P_y} \leq 0.5 \\ 4 \left(\frac{\alpha P_r}{P_y} \right) \left(1 - \frac{\alpha P_r}{P_y} \right) & \text{for } \frac{\alpha P_r}{P_y} \geq 0.5 \end{cases}$ B_1 and B_2 not used $K_2 = 1$ (used for P_n) Notional load with all combos, except for $\Delta_{2nd}/\Delta_{1st} \leq 1.5$ for which notional load with gravity combos only Notional load coefficient = 0.002 (typically) |

Table 2-1 The Essentials and Limitations of the Design Analysis Methods

| Direct Analysis Method | | | |
|--------------------------------|-------------------------------------|-----------------------------|---|
| Option | Variable | Limitation or Applicability | Essentials of the Method |
| | Fixed Factor Stiffness Reduction | No limitation | 2nd Order Analysis Reduced stiffness $EI^* = 0.8\tau_b EI$ $EA^* = 0.8EA$ $\tau_b = 1.0$ B_1 and B_2 not used $K_2 = 1$ (used for P_n) Notional load with all combos, except for $\Delta_{2nd}/\Delta_{1st} \leq 1.5$ for which notional load with gravity combos only Notional load coefficient = 0.003 (typically) |
| Amplified First Order Analysis | Variable Factor Stiffness Reduction | No limitation | 1st Order Analysis Reduced Stiffness $EI^* = 0.8\tau_b EI$ $EA^* = 0.8EA$ $\tau_b = \begin{cases} 1.0 & \text{for } \frac{\alpha P_r}{P_y} \leq 0.5 \\ 4 \left(\frac{\alpha P_r}{P_y} \right) \left(1 - \frac{\alpha P_r}{P_y} \right) & \text{for } \frac{\alpha P_r}{P_y} \geq 0.5 \end{cases}$ $K_1 = 1$ for B_1 $K_2 = 1$ for P_n and B_2 Notional load with all combos, except for $\Delta_{2nd}/\Delta_{1st} \leq 1.5$ for which notional load with gravity combos only Notional load coefficient = 0.002 (typically) |
| Amplified First Order Analysis | Fixed Factor Stiffness Reduction | No limitation | 2nd Order Analysis Reduced stiffness $EI^* = 0.8\tau_b EI$ $EA^* = 0.8EA$ $\tau_b = 1.0$ $K_2 = 1$ (used for P_n) Notional load with all combos, except for $\Delta_{2nd}/\Delta_{1st} \leq 1.5$ for which notional load with gravity combos only Notional load coefficient = 0.003 (typically) |
| Effective Length Method | | | |

Table 2-1 The Essentials and Limitations of the Design Analysis Methods

| Direct Analysis Method | | | |
|---------------------------------------|---|-----------------------------|--|
| Option | Variable | Limitation or Applicability | Essentials of the Method |
| Option | Limitation or Applicability | | Essentials of the Method |
| General Second Order Elastic Analysis | $\frac{\Delta_{2nd}}{\Delta_{1st}} \leq 1.5$ (for all stories) $\frac{\alpha P_r}{P_y} = any$ (for all columns) | | 2nd Order Analysis Unreduced Stiffness $K = K_2$ (used for P_n) Notional load with gravity combos only Notional load coefficient = 0.002 (typically) $B_1 = 1$ $B_2 = 1$ |
| Amplified First Order Analysis | $\frac{\Delta_{2nd}}{\Delta_{1st}} \leq 1.5$ (for all stories) $\frac{\alpha P_r}{P_y} = any$ (for all columns) | | 1st Order Analysis Unreduced stiffness K_1 for B_1 K_2 for B_2 $K = K_2$ (used for P_n) Notional load with gravity combos only Notional load with coefficient = 0.002 (typically) Use of B_1 and B_2 |
| Limited First Order Analysis | | | |
| Limited First Order Elastic Analysis | $\frac{\Delta_{2nd}}{\Delta_{1st}} \leq 1.5$ (for all stories) $\frac{\alpha P_r}{P_y} \leq 0.5$ (for all columns) | | 1st Order Analysis Unreduced stiffness K_2 for P_n (not B_2) Notional load with all combos Notional load with coefficient = $(2)\left(\frac{\Delta}{L}\right) \geq 0.0042$ |

The program has several limitations that have been stated in Section 1-5 and the preceding paragraphs. Additionally, the user must be aware that it is possible to choose a design option that violates certain provisions of the AISC code that will not be identified by the program. The limitation for the use of the effective length method, namely, the requirement that $\frac{\Delta_{2nd}}{\Delta_{1st}} \leq 1.5$ and $\frac{\alpha P_r}{P_e}$ must be verified by the user. To assist users to in making validity checks, the ratio $\frac{\alpha P_r}{P_e}$ and τ are now reported in tabular form for each member.

2.7 Notional Load Patterns

Notional loads are lateral loads that are applied at each framing level and are specified as a percentage of the gravity loads applied at that level. They are intended to account for the destabilizing effects of out-of-plumbness, geometric imperfections, inelasticity in structural members, and any other effects that could induce sway and that are not explicitly considered in the analysis.

The program allows the user to create a Notional Load pattern as a percentage of the previously defined gravity load pattern to be applied in one of the global lateral directions: X or Y. The user can define more than one notional load pattern associated with one gravity load by considering different factors and different directions. In the ANSI/AISC 360-05 code, the notional loads are typically suggested to be 0.2% (or 0.002) (AISC C2.2a, App. 7.3(2)), a factor referred to as the notional load coefficient in this document. The notional load coefficient can be 0.003 (AISC App 7.3(3)). In some cases, it can be a function of second order effects measured by relative story sway (AISC C2.26). The code also gives some flexibility to allow the engineer-of-record to apply judgment (AISC App. 7.3(2)).

The notional load patterns should be considered in combination with appropriate factors, appropriate directions, and appropriate senses. Some of the design analysis methods need the notional loads to be considered only in gravity load combinations (AISC App. 7.3(2)), and some of the methods need the notional loads to be considered in all the design load combinations (AISC App 7.3(2)). For a complete list, see Table 2-1 in the preceding "Second Order Effects and Analysis Methods" section of this chapter.

Currently, the notional loads are not automatically included in the default design load combinations that include lateral loads. However, the user is free to modify the default design load combinations to include the notional loads with appropriate factors and in appropriate load combinations.

2.8 Member Unsupported Lengths

The column unsupported lengths are required to account for column slenderness effects for flexural buckling and for lateral-torsional buckling. The

program automatically determines the unsupported length ratios, which are specified as a fraction of the frame object length. These ratios times the frame object lengths give the unbraced lengths for the member. These ratios can also be overwritten by the user on a member-by-member basis, if desired, using the overwrite option.

Two unsupported lengths, l_{33} and l_{22} , as shown in Figure 2-2 are to be considered for flexural buckling. These are the lengths between support points of the member in the corresponding directions. The length l_{33} corresponds to instability about the 3-3 axis (major axis), and l_{22} corresponds to instability about the 2-2 axis (minor axis). The length l_{LTB} , not shown in the figure, is also used for lateral-torsional buckling caused by major direction bending (i.e., about the 3-3 axis).

In determining the values for l_{22} and l_{33} of the members, the program recognizes various aspects of the structure that have an effect on these lengths, such as member connectivity, diaphragm constraints and support points. The program automatically locates the member support points and evaluates the corresponding unsupported length.

It is possible for the unsupported length of a frame object to be evaluated by the program as greater than the corresponding member length. For example, assume a column has a beam framing into it in one direction, but not the other, at a floor level. In this case, the column is assumed to be supported in one direction only at that story level, and its unsupported length in the other direction will exceed the story height.

By default, the unsupported length for lateral-torsional buckling, l_{LTB} , is taken to be equal to the l_{22} factor. Similar to l_{22} and l_{33} , l_{LTB} can be overwritten.

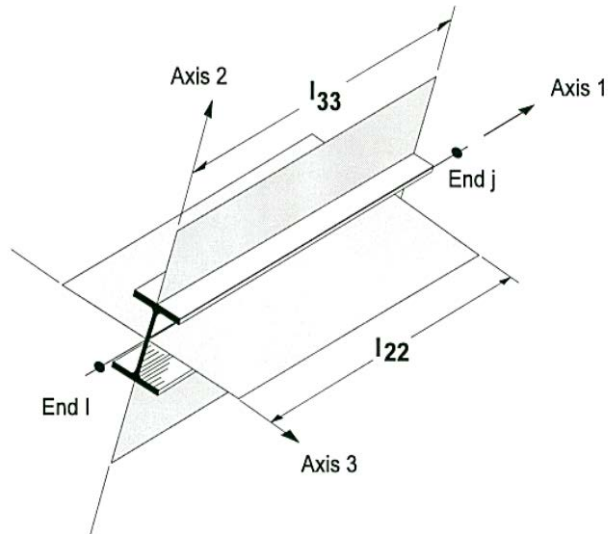


Figure 2-2 Unsupported lengths l_{33} and l_{22}

2.9 Effects of Breaking a Member into Multiple Elements

The preferred method is to model a beam, column or brace member as one single element. However, the user can request that the program break a member internally at framing intersections and at specified intervals. In this way, accuracy in modeling can be maintained, at the same time design/check specifications can be applied accurately. There is special emphasis on the end forces (moments in particular) for many different aspects of beam, column and brace design. If the member is manually meshed (broken) into segments, maintaining the integrity of the design algorithm becomes difficult.

Manually, breaking a column member into several elements can affect many things during design in the program.

1. The unbraced length: The unbraced length is really the unsupported length between braces. If there is no intermediate brace in the member, the unbraced length is typically calculated automatically by the program from the top of the flange of the beam framing the column at bottom to the bottom of the flange of the beam framing the column at the top. The automatically

calculated length factor typically becomes less than 1. If there are intermediate bracing points, the user should overwrite the unbraced length factor in the program. The user should choose the critical (larger) one. Even if the user breaks the element, the program typically picks up the unbraced length correctly, provided that there is no intermediate bracing point.

2. K -factor: Even if the user breaks the member into pieces, the program typically can pick up the K -factors correctly. However, sometimes it can not. The user should note the K -factors. All segments of the member should have the same K -factor and it should be calculated based on the entire member. If the calculated K -factor is not reasonable, the user can overwrite the K -factors for all the segments.
3. C_m factor: The C_m factor should be based on the end moments of unbraced lengths of each segment and should not be based on the end moments of the member. The program already calculates the C_m factors based on the end moments of unbraced lengths of each segment. If the break-up points are the brace points, no action is required by the user. If the broken segments do not represent the brace-to-brace unsupported length, the program calculated C_m factor is conservative. If this conservative value is acceptable, no action is required by the user. If it is not acceptable, the user can calculate the C_m factor manually for the critical combination and overwrite its value for that segment.
4. C_b factor: The logic is similar to that for the C_m factor.
5. B_1 factor: This factor amplifies the factored moments for the P - δ effect. In its expression, there are the C_m factor and the Euler Buckling capacity P_e . If the user keeps the unbraced length ratios (l_{33} and l_{22}) and the K -factors (K_{33} and K_{22}) correct, the B_1 factor would be correct. If the axial force is small, the B_1 factor can be 1 and have no effect with respect to modeling the single segment or multi-segment element.
6. B_2 factor: The program does not calculate the B_2 factor. The program assumes that the user turns on the P - Δ . In such cases, B_2 can be taken as equal to 1. That means the modeling with one or multiple segments has no effect on this factor.

If the user models a column with a single element and makes sure that the L -factors and K -factors are correct, the effect of B_1 and B_2 will be picked up correctly. The factors C_m and C_b will be picked up correctly if there is no intermediate bracing point. The calculated C_m and C_b factors will be slightly conservative if there are intermediate bracing points.

If the user models a column with multiple elements and makes sure that L -factors and K -factors are correct, the effect of B_1 and B_2 will be picked up correctly. The factors C_m and C_b will be picked up correctly if the member is broken at the bracing points. The calculated C_m and C_b factors will be conservative if the member is not broken at the bracing points.

2.10 Effective Length Factor (K)

The effective length method for calculating member axial compressive strength has been used in various forms in several stability based design codes. The method originates from calculating effective buckling lengths, KL , and is based on elastic/inelastic stability theory. The effective buckling length is used to calculate an axial compressive strength, P_n , through an empirical column curve that accounts for geometric imperfections, distributed yielding, and residual stresses present in the cross-section.

There are two types of K -factors in the ANSI/AISC 360-05 code. The first type of K -factor is used for calculating the Euler axial capacity assuming that all of the beam-column joints are held in place, i.e., no lateral translation is allowed. The resulting axial capacity is used in calculation of the B_1 factor. This K -factor is named as K_1 in the code. This K_1 factor is always less than 1 and is not calculated. By default the program uses the value of 1 for K_1 . The program allows the user to overwrite K_1 on a member-by-member basis.

The other K -factor is used for calculating the Euler axial capacity assuming that all the beam-column joints are free to sway, i.e., lateral translation is allowed. The resulting axial capacity is used in calculating P_n . This K -factor is named as K_2 in the code. This K_2 is always greater than 1 if the frame is a sway frame. The program calculates the K_2 factor automatically based on sway condition. The program also allows the user to overwrite K_2 factors on a

member-by-member basis. The same K_2 factor is supposed to be used in calculation of the B_2 factor. However the program does not calculate B_2 factors and relies on the overwritten values. If the frame is not really a sway frame, the user should overwrite the K_2 factors.

Both K_1 and K_2 have two values: one for major direction and the other for minor direction, K_{1minor} , K_{1major} , K_{2minor} , K_{2major} .

There is another K -factor, K_{ltb} for lateral torsional buckling. By default, K_{ltb} is taken as equal to K_{2minor} . However the user can overwrite this on a member-by-member basis.

The rest of this section is dedicated to the determination of K_2 factors.

The K -factor algorithm has been developed for building-type structures, where the columns are vertical and the beams are horizontal, and the behavior is basically that of a moment-resisting frame for which the K -factor calculation is relatively complex. For the purpose of calculating K -factors, the objects are identified as columns, beam and braces. All frame objects parallel to the Z -axis are classified as columns. All objects parallel to the X - Y plane are classified as beams. The remainders are considered to be braces.

The beams and braces are assigned K -factors of unity. In the calculation of the K -factors for a column object, the program first makes the following four stiffness summations for each joint in the structural model:

$$S_{cx} = \sum \left(\frac{E_c I_c}{L_c} \right)_x \qquad S_{bx} = \sum \left(\frac{E_b I_b}{L_b} \right)_x$$
$$S_{cy} = \sum \left(\frac{E_c I_c}{L_c} \right)_y \qquad S_{by} = \sum \left(\frac{E_b I_b}{L_b} \right)_y$$

where the x and y subscripts correspond to the global X and Y directions and the c and b subscripts refer to column and beam. The local 2-2 and 3-3 terms EI_{22}/L_{22} and EI_{33}/L_{33} are rotated to give components along the global X and Y directions to form the $(EI/L)_x$ and $(EI/L)_y$ values. Then for each column, the joint summations at END-I and the END-J of the member are transformed back to the column local 1-2-3 coordinate system, and the G -values for END-I

and the END-J of the member are calculated about the 2-2 and 3-3 directions as follows:

$$G^I_{22} = \frac{S^I_{c22}}{S^I_{b22}} \qquad G^J_{22} = \frac{S^J_{c22}}{S^J_{b22}}$$

$$G^I_{33} = \frac{S^I_{c33}}{S^I_{b33}} \qquad G^J_{33} = \frac{S^J_{c33}}{S^J_{b33}}$$

If a rotational release exists at a particular end (and direction) of an object, the corresponding value of G is set to 10.0. If all degrees of freedom for a particular joint are deleted, the G -values for all members connecting to that joint will be set to 1.0 for the end of the member connecting to that joint. Finally, if G^I and G^J are known for a particular direction, the column K -factors for the corresponding direction is calculated by solving the following relationship for α :

$$\frac{\alpha^2 G^I G^J - 36}{6(G^I + G^J)} = \frac{\alpha}{\tan \alpha}$$

from which $K = \pi/\alpha$. This relationship is the mathematical formulation for the evaluation of K -factors for moment-resisting frames assuming sidesway to be uninhibited. For other structures, such as braced frame structures, the K -factors for all members are usually unity and should be set so by the user. The following are some important aspects associated with the column K -factor algorithm:

- An object that has a pin at the joint under consideration will not enter the stiffness summations calculated above. An object that has a pin at the far end from the joint under consideration will contribute only 50% of the calculated EI value. Also, beam members that have no column member at the far end from the joint under consideration, such as cantilevers, will not enter the stiffness summation.
- If there are no beams framing into a particular direction of a column member, the associated G -value will be infinity. If the G -value at any one end of a column for a particular direction is infinity, the K -factor corresponding to that direction is set equal to unity.
- If rotational releases exist at both ends of an object for a particular direction, the corresponding K -factor is set to unity.

- The automated K -factor calculation procedure can occasionally generate artificially high K -factors, specifically under circumstances involving skewed beams, fixed support conditions, and under other conditions where the program may have difficulty recognizing that the members are laterally supported and K -factors of unity are to be used.
- All K -factors produced by the program can be overwritten by the user. These values should be reviewed and any unacceptable values should be replaced.
- The beams and braces are assigned K -factors of unity.

When a steel frame design is performed in accordance with ANSI/AISC 360-05 provision and the analysis method is chosen to be any of the four direct analysis methods, the K_{1b} and K_2 factors (K_{2minor} and K_{2major}) are automatically taken as 1 (AISC App. 7.1). However, their overwritten values are considered in design even if any of the Direct Analysis Methods is chosen.

2.11 Supported Framing Types

The code (ANSI/AISC 341-05) recognizes the following types of framing systems.

| Framing Type | References |
|---|-------------------|
| SMF (Special Moment Frame) | AISC SEISMIC 9 |
| IMF (Intermediate Moment Frame) | AISC SEISMIC 10 |
| OMF (Ordinary Moment Frame) | AISC SEISMIC 11 |
| STMF (Special Truss Moment Frame) | AISC SEISMIC 12 |
| SCBF (Special Concentrically Braced Frame) | AISC SEISMIC 13 |
| OCBF (Ordinary Concentrically Braced Frame) | AISC SEISMIC 14 |
| EBF (Eccentrically Braced Frame) | AISC SEISMIC 15 |
| BRBF (Buckling Restrained Braced Frame) | AISC SEISMIC 16 |
| SPSW (Special Plate Shear Wall) | AISC SEISMIC 17 |

With regard to these framing types, the program has implemented specifications for all types of framing systems, except STMF, BRBF, and SPSW. Implementing those three types of framing require further information about modeling.

The program recognizes the OCBF framing in its two separate incarnations: OCBF for regular Ordinary Concentrically Braced Frames (AISC SEISMIC 14) and OCBFI for (base) Isolated Ordinary Concentrically Braced Frames (AISC SEISMIC 14.5).

See Chapter 4 Special Seismic Provisions (ANSI/AISC 314-05) for additional requirements.

2.12 Continuity Plates

In a plan view of a beam/column connection, a steel beam can frame into a column in the following ways:

- The steel beam frames in a direction parallel to the column major direction, i.e., the beam frames into the column flange.
- The steel beam frames in a direction parallel to the column minor direction, i.e., the beam frames into the column web.
- The steel beam frames in a direction that is at an angle to both of the principal axes.

To achieve a beam/column moment connection, continuity plates, such as shown in Figure 2-3, are usually placed on the column, in line with the top and bottom flanges of the beam, to transfer the compression and tension flange forces of the beam into the column.

For connection conditions described in the last two bullet items, the thickness of such plates is usually set equal to the flange thickness of the corresponding beam.

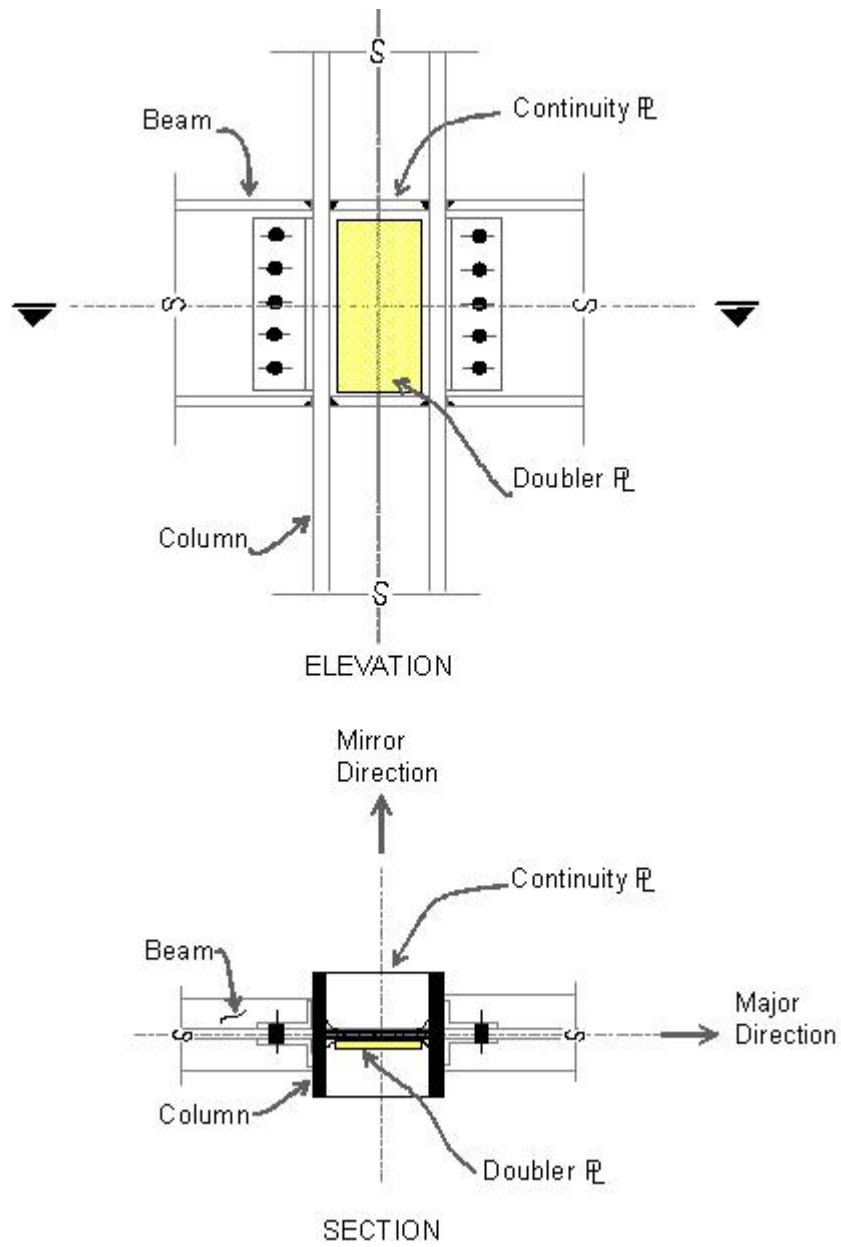


Figure 2-3 Doubler Plates and Continuity Plates

However, for the connection condition described by the first bullet item, where the beam frames into the flange of the column, such continuity plates are not always needed. The requirement depends upon the magnitude of the beam flange force and the properties of the column.

The program investigates whether the continuity plates are needed based on the requirements of the selected code. Columns of I-sections supporting beams of I-sections only are investigated. The program evaluates the continuity plate requirements for each of the beams that frame into the column flange and reports the maximum continuity plate area that is needed for each beam flange. The continuity plate requirements are evaluated for moment frames only.

2.13 Doubler Plates

One aspect of the design of a steel framing system is an evaluation of the shear forces that exist in the region of the beam column intersection known as the panel zone. Shear stresses seldom control the design of a beam or column member. However, in a moment resisting frame, the shear stress in the beam-column joint can be critical, especially in framing systems when the column is subjected to major direction bending and the web of the column resists the joint shear forces. In minor direction bending, the joint shear is carried by the column flanges, in which case the shear stresses are seldom critical, and the program does therefore not investigate this condition.

Shear stresses in the panel zone, due to major direction bending in the column, may require additional plates to be welded onto the column web, depending upon the loading and the geometry of the steel beams that frame into the column, either along the column major direction, or at an angle so that the beams have components along the column major direction. See Figure 3-3. When code appropriate, the program investigates such situations and reports the thickness of any required doubler plates. Only columns with I-shapes and only supporting beams with I-shapes are investigated for doubler plate requirements. Also, doubler plate requirements are evaluated for moment frames only.

2.14 Choice of Units

English as well as SI and MKS metric units can be used for input. The codes are based on a specific system of units. All equations and descriptions presented in the subsequent chapters correspond to that specific system of units unless otherwise noted. However, any system of units can be used to define and design a structure in the program.

It should be noted that two design processes are available in CSiBridge: superstructure design (on the Design/Rating tab) and design of the individual elements comprising the structure (the **Advanced > Frame Design** commands). This manual addresses the second design process.

Chapter 3

Design Using ANSI/AISC 360-05

This chapter provides a detailed description of the algorithms used by the programs in the design/check of structures in accordance with "ANSI/AISC 360-05 — Specifications for Structural Steel Building" (AISC 2005a, b). The menu option "AISC 360-05/IBC 2006" also covers the "ANSI/AISC 341-05 — Seismic Provisions for Structural Steel Building Including Supplement No. 1" (AISC 2005c), which is described in the next chapter. The implementation covers load combinations from "ASCE/SEI 7-05," which is described in the section "Design Loading Combinations" in this chapter. The loading based on "ASCE/SEI 7-05" has been described in a separate document entitled "CSI Lateral Load Manual" (CSI 2007). References also are made to IBC 2006 in this document.

For referring to pertinent sections of the corresponding code, a unique prefix is assigned for each code.

- Reference to the ANSI/AISC 360-05 code is identified with the prefix "**AISC.**"
- Reference to the ANSI/AISC 341-05 code is identified with the prefix "**AISC SEISMIC**" or sometimes "**SEISMIC**" only.
- Reference to the ASCE/SEI 7-05 code is identified with the prefix "**ASCE.**"
- Reference to the IBC 2006 code is identified with the prefix "**IBC.**"

3.1 Notations

The various notations used in this chapter are described herein.

| | |
|------------------|--|
| A | Cross-sectional area, in ² |
| A_e | Effective cross-sectional area for slender sections, in ² |
| A_g | Gross cross-sectional area, in ² |
| A_{v2}, A_{v3} | Major and minor shear areas, in ² |
| A_w | Shear area, equal dt_w per web, in ² |
| B_1 | Moment magnification factor for moments not causing sidesway |
| B_2 | Moment magnification factor for moments causing sidesway |
| C_b | Bending coefficient |
| C_m | Moment coefficient |
| C_w | Warping constant, in ⁶ |
| D | Outside diameter of pipes, in |
| E | Modulus of elasticity, ksi |
| F_{cr} | Critical compressive stress, ksi |
| F_r | Compressive residual stress in flange assumed 10.0 for rolled sections and 16.5 for welded sections, ksi |
| F_y | Yield stress of material, ksi |
| G | Shear modulus, ksi |
| I_{22} | Minor moment of inertia, in ⁴ |
| I_{33} | Major moment of inertia, in ⁴ |
| J | Torsional constant for the section, in ⁴ |

| | |
|--------------------|---|
| K | Effective length factor |
| K_1 | Effective length factor for braced condition |
| K_2 | Effective length factor for unbraced condition |
| K_{33}, K_{22} | Effective length K -factors in the major and minor directions for appropriate braced (K_1) and unbraced (K_2) condition |
| L_b | Laterally unbraced length of member, in |
| L_p | Limiting laterally unbraced length for full plastic capacity, in |
| L_r | Limiting laterally unbraced length for inelastic lateral-torsional buckling, in |
| M_{cr} | Elastic buckling moment, kip-in |
| M_{lt} | Factored moments causing sidesway, kip-in |
| M_{nt} | Factored moments not causing sidesway, kip-in |
| M_{n33}, M_{n22} | Nominal bending strength in major and minor directions, kip-in |
| M_{ob} | Elastic lateral-torsional buckling moment for angle sections, kip-in |
| M_{r33}, M_{r22} | Major and minor limiting buckling moments, kip-in |
| M_u | Factored moment in member, kip-in |
| M_{u33}, M_{u22} | Factored major and minor moments in member, kip-in |
| P_e | Euler buckling load, kips |
| P_n | Nominal axial load strength, kip |
| P_u | Factored axial force in member, kips |
| P_y | $A_g F_y$, kips |
| Q | Reduction factor for slender section, = $Q_a Q_s$ |
| Q_a | Reduction factor for stiffened slender elements |

| | |
|--------------------------|---|
| Q_s | Reduction factor for unstiffened slender elements |
| S | Section modulus, in ³ |
| S_{33}, S_{22} | Major and minor section moduli, in ³ |
| $S_{eff,33}, S_{eff,22}$ | Effective major and minor section moduli for slender sections, in ³ |
| S_c | Section modulus for compression in an angle section, in ³ |
| V_{n2}, V_{n3} | Nominal major and minor shear strengths, kips |
| V_{u2}, V_{u3} | Factored major and minor shear loads, kips |
| Z | Plastic modulus, in ³ |
| Z_{33}, Z_{22} | Major and minor plastic moduli, in ³ |
| b | Nominal dimension of plate in a section, in longer leg of angle sections, $b_f - 2t_w$ for welded and $b_f - 3t_w$ for rolled box sections, and the like |
| b_e | Effective width of flange, in |
| b_f | Flange width, in |
| d | Overall depth of member, in |
| d_e | Effective depth of web, in |
| h_c | Clear distance between flanges less fillets, in assumed $d - 2k$ for rolled sections, and $d - 2t_f$ for welded sections |
| k | Distance from outer face of flange to web toe of fillet, in |
| k_c | Parameter used for section classification $k_c = 4/\sqrt{h/t_w}$, $0.35 \leq k_c \leq 0.763$ |
| l_{33}, l_{22} | Major and minor directions unbraced member lengths, in |
| r | Radius of gyration, in |

| | |
|------------------------|---|
| r_{33}, r_{22} | Radii of gyration in the major and minor directions, in |
| t | Thickness, in |
| t_f | Flange thickness, in |
| t_w | Thickness of web, in |
| β_w | Special section property for angles, in |
| λ | Slenderness parameter |
| λ_c, λ_e | Column slenderness parameters |
| λ_p | Limiting slenderness parameter for compact element |
| λ_r | Limiting slenderness parameter for non-compact element |
| λ_s | Limiting slenderness parameter for seismic element |
| $\lambda_{slender}$ | Limiting slenderness parameter for slender element |
| ϕ_b | Resistance factor for bending |
| ϕ_c | Resistance factor for compression |
| ϕ_t | Resistance factor for tension yielding |
| ϕ_T | Resistance factor for torsion |
| ϕ_v | Resistance factor for shear |
| Ω_b | Safety factor for bending |
| Ω_c | Safety factor for compression |
| Ω_t | Safety factor for tension |
| Ω_T | Safety factor for torsion |
| Ω_v | Safety factor for shear |

3.2 Design Loading Combinations

The structure is to be designed so that its design strength equals or exceeds the effects of factored loads stipulated by the applicable design code. The default design combinations are the various combinations of the already defined load cases, such as dead load (DL), live load (LL), roof live load (RL), snow load (SL), wind load (WL), and horizontal earthquake load (EL).

AISC 360-05 refers to the applicable building code for the loads and load combinations to be considered in the design, and to ASCE 7-05 in the absence of such a building code. Hence, the default design combinations used in the current version are the ones stipulated in ASCE 7-05:

For design in accordance with LRFD provisions:

| | |
|-----------------------------------|----------------|
| 1.4 DL | (ASCE 2.3.2-1) |
| 1.2 DL + 1.6 LL + 0.5 RL | (ASCE 2.3.2-2) |
| 1.2 DL + 1.0 LL + 1.6 RL | (ASCE 2.3.2-3) |
| 1.2 DL + 1.6 LL + 0.5 SL | (ASCE 2.3.2-2) |
| 1.2 DL + 1.0 LL + 1.6 SL | (ASCE 2.3.2-3) |
| 0.9 DL ± 1.6 WL | (ASCE 2.3.2-6) |
| 1.2 DL + 1.6 RL ± 0.8 WL | (ASCE 2.3.2-3) |
| 1.2 DL + 1.0 LL + 0.5RL ± 1.6 WL | (ASCE 2.3.2-4) |
| 1.2 DL + 1.6 SL ± 0.8 WL | (ASCE 2.3.2-3) |
| 1.2 DL + 1.0 LL + 0.5SL ± 1.06 WL | (ASCE 2.3.2-4) |
| 0.9 DL ± 1.0 EL | (ASCE 2.3.2-7) |
| 1.2 DL + 1.0 LL + 0.2SL ± 1.0EL | (ASCE 2.3.2-5) |

For design in accordance with ASD provisions:

| | |
|----------------------------|----------------|
| 1.0 DL | (ASCE 2.4.1-1) |
| 1.0 DL + 1.0 LL | (ASCE 2.4.1-2) |
| 1.0 DL + 1.0 RL | (ASCE 2.4.1-3) |
| 1.0 DL + 0.75 LL + 0.75 RL | (ASCE 2.3.2-4) |
| 1.0 DL + 1.0 SL | (ASCE 2.4.1-3) |
| 1.0 DL + 0.75 LL + 0.75 SL | (ASCE 2.3.2-4) |

| | |
|---|----------------|
| 1.0 DL ± 1.0 WL | (ASCE 2.4.1-5) |
| 1.0 DL + 0.75 LL + 0.75 RL ± 0.75 (WL) | (ASCE 2.4.1-6) |
| 1.0 DL + 0.75 LL + 0.75 SL ± 0.75 (WL) | (ASCE 2.4.1-6) |
| 0.6 DL ± 1.0 WL | (ASCE 2.4.1-7) |
| 1.0 DL ± 0.7 EL | (ASCE 2.4.1-5) |
| 1.0 DL + 0.75 LL + 0.75 SL ± 0.75(0.7 EL) | (ASCE 2.4.1-6) |
| 0.6 DL ± 0.7 EL | (ASCE 2.4.1-8) |

Most of the analysis methods recognized by the code are required to consider Notional Load in the design loading combinations for steel frame design. The program allows the user to define and create notional loads as individual load cases from a specified percentage of a given gravity load acting in a particular lateral direction. These notional load patterns should be considered in the combinations with appropriate factors, appropriate directions, and appropriate senses. Currently, the program automatically includes the notional loads in the default design load combinations for gravity combinations only. The user is free to modify the default design load combinations to include the notional loads. For further information, refer to the "Notional Load Patterns" section in Chapter 2.

The program automatically considers seismic load effects, including overstrength factors (ASCE 12.4.3), as special load combinations that are created automatically from each load combination, involving seismic loads. In that case, the horizontal component of the force is represented by E_{hm} and the vertical component of the force is represented by E_v , where

$$E_{hm} = \Omega_0 Q_E \quad (\text{ASCE 12.4.3.1})$$

$$E_v = 0.2 S_{DS} D \quad (\text{ASCE 12.4.2.2})$$

where, Ω_o is the overstrength factor and it is taken from ASCE 7-05 Table 12.2-1. The factor S_{DS} is described later in this section. Effectively, the special seismic combinations that are considered for the LRFD provision are

$$(0.9 - 0.2 S_{DS}) DL \pm \Omega_0 Q_E \quad (\text{ASCE 12.4.3.2})$$

$$(1.2 - 0.2 S_{DS}) DL \pm \Omega_0 Q_E + 1.0 LL \quad (\text{ASCE 12.4.3.2})$$

and for the ASD provision the combinations are

$$(1.0 - 0.14 S_{DS}) DL \pm 0.7 \Omega_0 Q_E \quad (\text{ASCE 12.4.3.2})$$

$$(1.0 + 0.105S_{DS})DL \pm 0.75(0.7\Omega_0)Q_E + 0.75LL \quad (\text{ASCE 12.4.3.2})$$

$$(0.6 - 0.14S_{DS})DL \pm 0.7\Omega_0Q_E \quad (\text{ASCE 12.4.3.2})$$

The program assumes that the defined earthquake load is really the strength level earthquake, which is equivalent to Q_E as defined in Section 12.4.2.1 of the ASCE 7-05 code. For regular earthquake, load is considered to have two components: horizontal, E_h and vertical E_v , which are taken as

$$E_h = \rho\theta_E \quad (\text{ASCE 12.4.2.1})$$

$$E_v = 0.2S_{DS}D \quad (\text{ASCE 12.4.2.2})$$

where, ρ is the redundancy factor as defined in Section 12.3.4 of ASCE 7-05, and the S_{DS} is the design earthquake spectral response acceleration parameters at short periods, as defined in Section 11.4.4 of ASCE 7-05 code.

Effectively, the seismic load combination for the LRFD provision becomes:

$$(1.2 + 0.2S_{DS})DL \pm \rho Q_E \quad (\text{ASCE 2.3.2-5, 12.4.2.3})$$

$$(1.2 + 0.2S_{DS})DL \pm \rho Q_E + 1.0LL \quad (\text{ASCE 2.3.2-5, 12.4.2.3})$$

$$(0.9 - 0.2S_{DS})DL \pm \rho Q_E \quad (\text{ASCE 2.3.2-7, 12.4.2.3})$$

The seismic load combinations for the ASD provision become:

$$(1.0 + 0.14S_{DS})DL \pm 0.7\rho Q_E \quad (\text{ASCE 2.4.1-5, 12.4.2.3})$$

$$(1.0 + 0.105S_{DS})DL \pm 0.75(0.7\rho)Q_E + 0.75LL \quad (\text{ASCE 2.4.1-6, 12.4.2.3})$$

$$(0.6 - 0.14S_{DS})DL \pm 0.7\rho Q_E \quad (\text{ASCE 2.4.1-7, 12.4.2.3})$$

The program assumes that the seismic loads defined as the strength level load is the program load case. Otherwise, the factors ρ , Ω_0 , and S_{DS} will not be able to scale the load to the desired level.

The combinations described herein are the default loading combinations only. They can be deleted or edited as required by the design code or engineer-of-record.

The program allows live load reduction factors to be applied to the member forces of the reducible live load case on a member-by-member basis to reduce the contribution of the live load to the factored responses.

3.3 Classification of Sections for Local Buckling

The nominal strengths for axial, compression, and flexure are dependent on the classification of the section as Seismically Compact, Compact, Noncompact, Slender, or Too Slender. Compact or Seismically Compact sections are capable of developing the full plastic strength before local buckling occurs. Noncompact sections can develop partial yielding in compression, and buckle inelastically before reaching to a fully plastic stress distribution. Slender sections buckle elastically before any of the elements yield under compression. Seismically Compact sections are capable of developing the full plastic strength before local buckling occurs when the section goes through low cycle fatigue and withstands reversal of load under seismic conditions.

Sections are classified as Compact, Noncompact, or Slender sections in accordance with Section B4 of the code (AISC B4). For a section to qualify as Compact, its flanges must be continuously connected to the web or webs and the width-thickness ratios of its compression elements must not exceed the limiting width-thickness ratios λ_p from Table B4.1 of the code. If the width-thickness ratio of one or more compression elements exceeds λ_p , but does not exceed λ_r from Table B4.1, the section is Noncompact. If the width-thickness ratio of any element exceeds λ_r but does not exceed λ_s , the section is Slender. If the width-thickness ratio of any element exceed λ_s , the section is considered Too Slender. The expressions of λ_p , λ_r , and λ_s , as implemented in the program, are reported in Table 3-1 (AISC Table B4.1, B4, F8, F13.2). In that table all expressions of λ_p and λ_r are taken from AISC section B4 and AISC Table B4.1. The limit demarcating Slender and Too Slender has been identified as λ_s in this document. The expressions of λ_s for I-Shape, Double Channel, Channel and T-Shape sections are taken from AISC section F13.2. The expression of λ_s for Pipe Sections is taken from AISC section F8. The expression of λ_p for Angle and Double Angle sections is taken from AISC Seismic code ANSI/AISC 341-05 Table I-8-1.

The table uses the variables k_c , F_L , h , h_p , h_c , b_f , t_f , t_w , b , t , D , d , and so on. The variables b , d , D and t are explained in the respective figures inside the table. The variables b_f , t_f , h , h_p , h_c , and t_w are explained in Figure 3-1. For Doubly Symmetric I-Shapes, h , h_p , and h_c are all equal to each other.

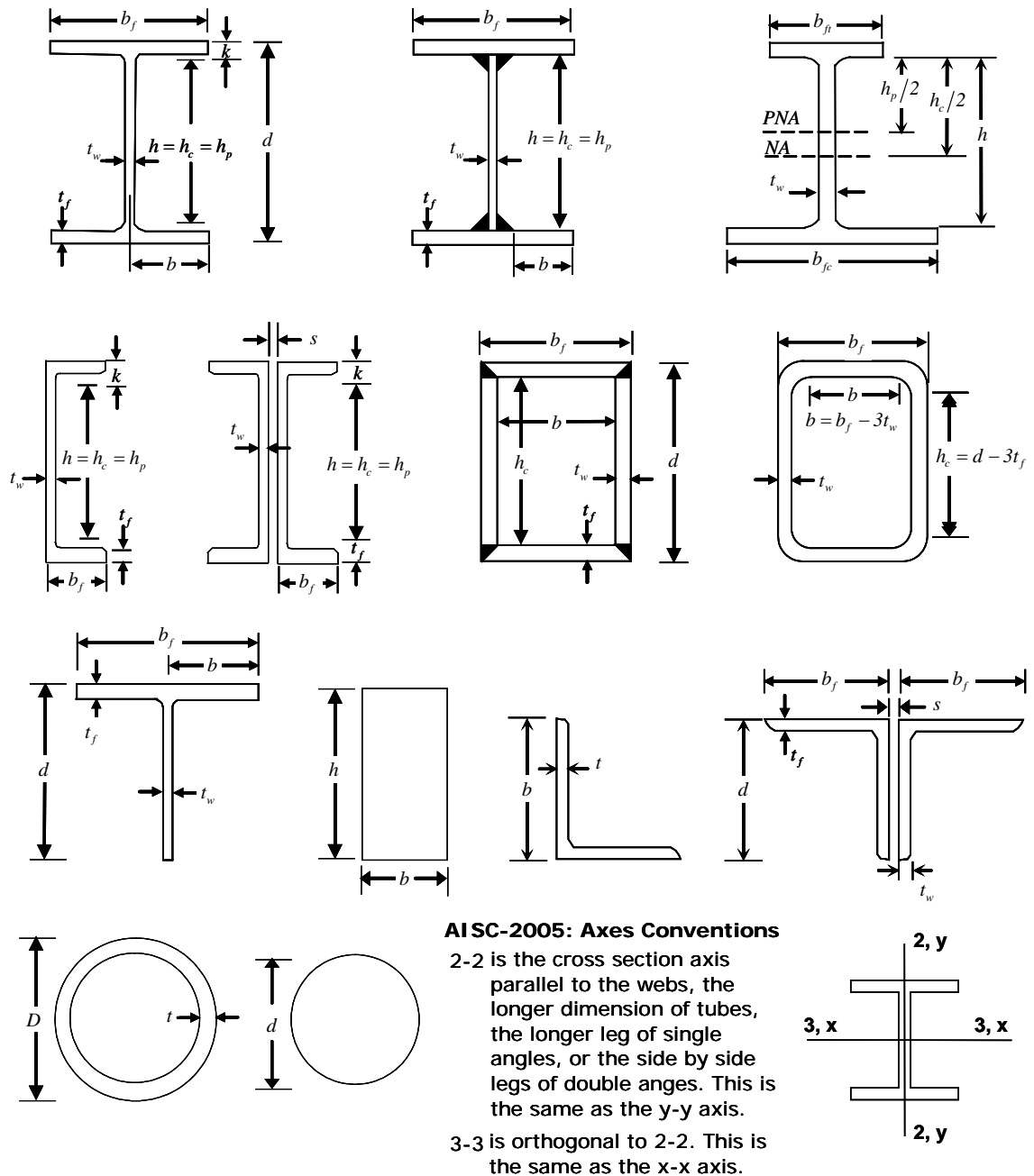


Figure 3-1 AISC 360-05 Definition of Geometric Properties

For unstiffened elements supported along only one edge parallel to the direction of compression force, the width shall be taken as follows:

- (a) For flanges of I-shaped members and tees, the width b is one-half the full-flange width, b_f .
- (b) For legs of angles and flanges of channels and zees, the width b is the full nominal dimension.
- (c) For plates, the width b is the distance from the free edge to the first row of fasteners or line of welds.
- (d) For stems of tees, d is taken as the full nominal depth of the section.

Refer to Table 3-1 (AISC Table B4.1) for the graphic representation of unstiffened element dimensions.

For stiffness elements supported along two edges parallel to the direction of the compression force, the width shall be taken as follows:

- (a) For webs of rolled or formed sections, h is the clear distance between flanges less the fillet or corner radius at each flange; h_c is twice the distance from the centroid to the inside face of the compression flange less the fillet or corner radius.
- (b) For webs of built-up sections, h is the distance between adjacent lines of fasteners or the clear distance between flanges when welds are used, and h_c is twice the distance from the centroid to the nearest line of fasteners at the compression flange or the inside face of the compression flange when welds are used; h_p is twice the distance from the plastic neutral axis to the nearest line of fasteners at the compression flange or the inside face of the compression flange when welds are used.
- (c) For flange or diaphragm plates in built-up sections, the width b is the distance between adjacent lines of fasteners or lines of welds.

Table 3-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

| Section Type | Description of Element | Example | AISC Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Element | | |
|---------------------------|--|---------|---------------|------------------------------------|---|--------------------------|---|
| | | | | | Compact (λ_p) | NonCompact (λ_r) | Slender (λ_s) |
| Doubly Symmetric I-Shape | Flexural compression of flanges of rolled I-Shapes | | 1 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $1.0\sqrt{E/F_y}$ | No Limit |
| | Flexural compression in flanges of built-up I-Shapes | | 2 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.95\sqrt{k_c E/F_L}$ | No Limit |
| | Axial only compression in flanges of rolled I-Shapes | | 3 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.56\sqrt{E/F_y}$ | No Limit |
| | Axial only compression in flanges of built-up I-Shapes | | 4 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.64\sqrt{k_c E/F_L}$ | No Limit |
| | Flexure in web | | 9 | h/t_w | $3.76\sqrt{E/F_y}$ | $5.70\sqrt{E/F_y}$ | $\min\{0.42 E/F_y, 260\}$ (beams) No limit for columns and braces |
| | Web in axial only compression | | 10 | h/t_w | NA | $1.49\sqrt{E/F_y}$ | $\min\{0.42 E/F_y, 260\}$ (beams) No limit for columns and braces |
| Singly Symmetric I-Shapes | Flexural Compression of flanges of rolled I-Shapes | | 1 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $1.0\sqrt{E/F_y}$ | No Limit |

Table 3-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

| Section Type | Description of Element | Example | AISC Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Element | | |
|---------------------------------------|--|---------|---------------|------------------------------------|---|--------------------------|---|
| | | | | | Compact (λ_p) | NonCompact (λ_r) | Slender (λ_s) |
| Singly Symmetric I-Shapes (continued) | Flexural Compression in flanges of built-up I-Shapes | | 2 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.95\sqrt{k_c E/F_L}$ | No Limit |
| | Axial only compression in flanges of rolled I-Shapes | | 3 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.56\sqrt{E/F_y}$ | No Limit |
| | Axial only compression in flanges of built-up I-Shapes | | 4 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $0.64\sqrt{k_c E/F_L}$ | No Limit |
| | Flexure in Web | | 11 | h_c/t_w | $\frac{h_c}{h_p} \sqrt{\frac{E}{F_y}}$ $\left(\frac{0.54 M_p}{M_y} - 0.09 \right) \leq \lambda_r$ | $5.70\sqrt{E/F_y}$ | No Limit |
| | Flexure in Web | | | h/t_w | NA | NA | $\min\{0.42 E/F_y, 260\}$ (beams) No limit for columns and braces |
| Channel | Flexural compression in flanges | | 1 | b_f/t_f | $0.38\sqrt{E/F_y}$ | $1.0\sqrt{E/F_y}$ | No Limit |
| | Axial only compression in flanges | | 3 | b_f/t_f | $0.38\sqrt{E/F_y}$ | $0.56\sqrt{E/F_y}$ | No Limit |

Table 3-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

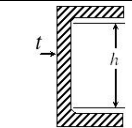
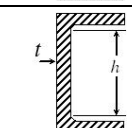
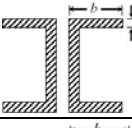
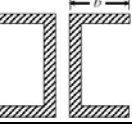
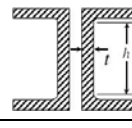
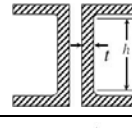
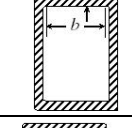
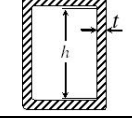
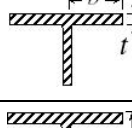
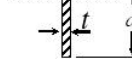
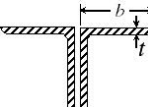
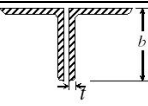
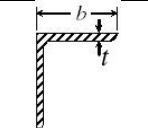
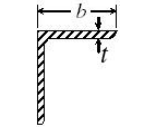
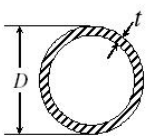
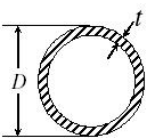
| Section Type | Description of Element | Example | AISC Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Element | | |
|---------------------|---|---|---------------|------------------------------------|---|--------------------------|--|
| | | | | | Compact (λ_p) | NonCompact (λ_r) | Slender (λ_s) |
| Channel (continued) | Flexure in web |  | 9 | h/t_w | $3.76\sqrt{E/F_y}$ | $5.70\sqrt{E/F_y}$ | $\min\{0.42E/F_y, 260\}$ (beams) No limit for columns and braces |
| | Web in axial only compression |  | 10 | h/t_w | NA | $1.49\sqrt{E/F_y}$ | $\min\{0.42E/F_y, 260\}$ (beams) No limit for columns and braces |
| Double Channel | Flexural compression in flanges |  | 1 | b_f/t_f | $0.38\sqrt{E/F_y}$ | $1.0\sqrt{E/F_y}$ | No Limit |
| | Axial only compression in flanges |  | 3 | b_f/t_f | $0.38\sqrt{E/F_y}$ | $0.56\sqrt{E/F_y}$ | No Limit |
| | Flexure in web |  | 9 | h/t_w | $3.76\sqrt{E/F_y}$ | $5.70\sqrt{E/F_y}$ | $\min\{0.42E/F_y, 260\}$ (beams) No limit for columns and braces |
| | Web in axial only compression |  | 10 | h/t_w | NA | $1.49\sqrt{E/F_y}$ | $\min\{0.42E/F_y, 260\}$ (beams) No limit for columns and braces |
| Box | Flexural or axial compression of flanges under major axis bending |  | 12 | b/t | $1.12\sqrt{E/F_y}$ | $1.40\sqrt{E/F_y}$ | No Limit |
| | Flexure in web |  | 13 | h/t | $2.42\sqrt{E/F_y}$ | $5.70\sqrt{E/F_y}$ | No Limit |
| T-Shape | Flexural or axial compression in flanges |  | 7 | $b_f/2t_f$ | $0.38\sqrt{E/F_y}$ | $1.0\sqrt{E/F_y}$ | No Limit |
| | Compression in stems |  | 8 | d/t_w | $0.30\sqrt{E/F_y}$ | $0.75\sqrt{E/F_y}$ | No Limit |

Table 3-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

| Section Type | Description of Element | Example | AISC Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Element | | |
|--------------|-----------------------------------|---|---------------|------------------------------------|---|--------------------------|-----------------------|
| | | | | | Compact (λ_p) | NonCompact (λ_r) | Slender (λ_s) |
| Double Angle | Any type of compression in leg |  | 6 | b/t | $0.30\sqrt{E/F_y}$ | $0.45\sqrt{E/F_y}$ | No Limit |
| | Any type of compression in leg |  | 6 | b/t | $0.30\sqrt{E/F_y}$ | $0.45\sqrt{E/F_y}$ | No Limit |
| Angle | Flexural compression in any leg |  | 7 | b/t | $0.54\sqrt{E/F_y}$ | $0.91\sqrt{E/F_y}$ | No Limit |
| | Axial only compression in any leg |  | 6 | b/t | $0.30\sqrt{E/F_y}$ | $0.45\sqrt{E/F_y}$ | No Limit |
| Pipe | Flexural compression |  | 15 | D/t | $0.07\sqrt{E/F_y}$ | $0.31E/F_y$ | $0.45E/F_y$ |
| | Axial only compression |  | 15 | D/t | $0.07\sqrt{E/F_y}$ | $0.11E/F_y$ | $0.45E/F_y$ |
| Round Bar | ---- | ---- | --- | ---- | Assumed Noncompact | | |
| Rectangular | ---- | ---- | --- | ---- | Assumed Noncompact | | |
| General | ---- | ---- | --- | ---- | Assumed Noncompact | | |
| SD Section | ---- | ---- | --- | ---- | Assumed Noncompact | | |

(d) For flanges of rectangular hollow structural sections (HSS), the width b is the clear distance between webs less the inside corner radius on each side. For webs of rectangular HSS, h is the clear distance between the flanges less the inside corner radius on each side. If the corner radius is not known, b and h shall be taken as the corresponding outside dimension minus three times the thickness. The thickness, t , shall be taken as the design wall thickness, in accordance with AISC Section B3.12.

Refer to Table 3-5 (AISC Table B4.1) for the graphic representation of stiffened element dimensions.

The design wall thickness, t , for hollow structural sections, such as Box and Pipe sections, is modified for the welding process (AISC B3.12). If the welding process is ERW (Electric-Resistance Welding), the thickness is reduced by a factor of 0.93. However, if the welding process is SAW (Submerged Arc Welded), the thickness is not reduced. The Overwrites can be used to choose if the thickness of HSS sections should be reduced for ERW on a member-by-member basis. The Overwrites can also be used to change the reduction factor.

The variable k_c can be expressed as follows:

$$k_c = \frac{4}{\sqrt{h/t_w}}, \quad (\text{AISC Table B4.1 Note a})$$

$$0.35 \leq k_c \leq 0.76. \quad (\text{AISC Table B4.1 Note a})$$

For Doubly Symmetric I-Shapes, Channels, and Double Channels, F_L can be expressed as follows:

$$F_L = 0.7F_y, \quad (\text{AISC Table B4.1 Note b})$$

and for Singly Symmetric I-Shape sections, F_L can be expressed as follows:

$$F_L = \frac{S_{xt}}{S_{xc}} F_y, \quad \text{where} \quad (\text{AISC Table B4.1 Note b, F4-6})$$

$$0.5F_y \leq F_L \leq 0.7F_y. \quad (\text{AISC Table B4.1 Note b, F4-6})$$

Seismically Compact sections are compact sections that satisfy a more stringent width-thickness ratio limit, λ_{ps} . This limit λ_{ps} is presented in Table 4-1 in Chapter 4, which is dedicated to the seismic code.

In classifying web slenderness of I-Shapes, Box, Channel, Double Channel, and all other sections, it is assumed that there are no intermediate stiffeners. Double angles and channels are conservatively assumed to be separated.

Stress check of Too Slender sections is beyond the scope of this program.

3.4 Calculation of Factored Forces and Moments

The factored member loads that are calculated for each load combination are P_r , M_{r33} , M_{r22} , V_{r2} , V_{r3} and T_r corresponding to factored values of the axial load, the major and minor moments and shears, and torsion, respectively. These factored loads are calculated at each of the previously defined stations.

The factored forces can be amplified to consider second order effects, depending on the choice of analysis method chosen in the Preferences. If the analysis method is chosen to be General Second Order Elastic Analysis or any of the Direct Analysis methods with General Second Order Analysis, it is assumed that the analysis considers the influence of second-order effects (P- Δ and P- δ effects); hence the analysis results are used without amplification (AISC C2.1, C2.2a, App 7.3). Second-order effects due to overall sway of the structure can usually be accounted for, conservatively, by considering the second-order effects on the structure under one set of loads (usually the most severe gravity load case), and performing all other analyses as linear using the stiffness matrix developed for this one set of P-delta loads (see also White and Hajjar 1991). For a more accurate analysis, it is always possible to define each loading combination as a nonlinear load case that considers only geometric nonlinearities. For both approaches, when P- δ effects are expected to be important, use more than one element per line object (accomplished using the automatic frame subdivide option; refer to the program Help for more information about automatic frame subdivide).

If the analysis method is chosen to be Second Order Analysis by Amplified First Order Analysis or any of the Direct Analysis Methods with Amplified First Order Analysis (AISC C2.1b, C2.2, App 7.3), it is assumed that the analysis does not consider the influence of second order effects (P- Δ and P- δ). Hence the analysis results are amplified using B_1 and B_2 factors using the following approximate second-order analysis for calculating the required flexural and axial strengths in members of lateral load resisting systems. The required second-order flexural strength, M_r , and axial strength, P_r are determined as follows:

$$M_r = B_1 M_{nt} + B_2 M_{lt} \quad (\text{AISC C2-1a})$$

$$P_r = P_{nt} + B_2 P_{lt} \quad (\text{AISC C2-1b})$$

where,

$$B_1 = \frac{C_m}{1 - \alpha \frac{P_r}{P_{e1}}} \geq 1, \text{ and} \quad (\text{AISC C2-2})$$

$$B_2 = \frac{1}{1 - \frac{\alpha \Sigma P_{nt}}{\Sigma P_{e2}}} \geq 1, \quad (\text{AISC C2-3})$$

where,

$$\alpha = \begin{cases} 1.0 & \text{for LRFD,} \\ 1.6 & \text{for ASD,} \end{cases}$$

M_r = required second-order flexural strength using LRFD and ASD load combinations, kip-in (N-mm)

M_{nt} = first-order moment using LRFD and ASD load combinations, assuming there is no lateral translation of the frame, kip-in. (N-mm)

M_{lt} = first-order moment using LRFD or ASD load combinations caused by lateral translation of the frame only, kip-in (N-mm)

P_r = required second-order axial strength using LRFD or ASD load combinations, kip (N)

P_{nt} = first-order axial force using LRFD or ASD load combinations, assuming there is no lateral translation of the frame, kips (N)

ΣP_{nt} = total vertical load supported by the story using LRFD or ASD load combinations, including gravity column loads, kips (N)

P_{lt} = first-order axial force using LRFD or ASD load combinations caused by lateral translation of the frame only, kips (N)

C_m = a coefficient assuming no lateral translation of the frame, whose value is taken as follows:

- (i) For beam-columns not subject to transverse loading between supports in the plane of bending,

$$C_m = 0.6 - 0.4(M_a/M_b), \quad (\text{AISC C2-4})$$

where, M_a and M_b , calculated from a first-order analysis, are the smaller and larger moments, respectively, at the ends of that portion of the member unbraced in the plane of bending under consideration. M_a/M_b is positive when the member is bent in reverse curvature, negative when bent in single curvature.

- (ii) For beam-columns subjected to transverse loading between supports, the value of C_m is conservatively taken as 1.0 for all cases.

When M_b is zero, C_m is taken as 1.0, the program defaults C_m to 1.0, if the unbraced length is more than actual member length. The user can overwrite the value of C_m for any member. C_m can be expressed as follows:

$$C_m = \begin{cases} 1.00, & \text{if length is more than actual length,} \\ 1.00, & \text{if tension member,} \\ 1.00, & \text{if both ends unrestrained,} \\ 0.6 - 0.4 \frac{M_a}{M_b}, & \text{if no transverse loading, and} \\ 1.00, & \text{if transverse loading is present.} \end{cases} \quad (\text{AISC C2-1b})$$

P_{el} = elastic critical buckling resistance of the member in the plane of bending, calculated based on the assumption of zero side-sway, kips (N)

$$P_{el} = \frac{\pi^2 EI}{(K_1 L)^2} \quad (\text{AISC C2-5})$$

If any of the direct analysis methods are used, the reduced value of EI is used (AISC App. 7.3(1)).

ΣP_{e2} = elastic critical buckling resistance for the story determined by sidesway buckling analysis, kips (N)

For moment frames, where sidesway buckling effective length factors K_2 are determined for the columns, it is the elastic story sidesway buckling resistance and calculated as

$$\Sigma P_{e2} = \Sigma \frac{\pi^2 EI}{(K_2 L)^2}, \quad (\text{AISC C2-6a})$$

where,

E = modulus of elasticity of steel = 29,000 ksi (200,000 MPa)

If any of the direct analysis methods are used, the reduced value of EI is used (AISC App. 7.3(1)).

I = moment of inertia in the plane of bending, in.⁴ (mm⁴)

L = story height, in. (mm)

K_1 = effective length factor in the plane of bending, calculated based on the assumption of no lateral translation. It is taken to be equal to 1.0, conservatively. The Overwrites can be used to change the value of K_1 for the major and minor directions.

K_2 = effective length factor in the plane of bending, calculated based on a sidesway buckling analysis. The Overwrites can be used to change the value of K_2 for the major and minor directions.

In the expression of B_1 , the required axial force P_r is used based on its first order value. The magnification factor B_1 must be a positive number. Therefore, αP_r must be less than P_{e1} . If αP_r is found to be greater than or equal to P_{e1} a failure condition is declared.

If the program assumptions are not satisfactory for a particular structural model or member, the user has the choice to explicitly specify the values of B_1 for any member.

Currently, the program does not calculate the B_2 factor. The user is required to overwrite the values of B_2 for the members.

3.5 Calculation of Nominal Strengths

The nominal strengths in compression, tension, bending, and shear are computed for Compact, Noncompact, and Slender members in accordance with the following sections. The nominal flexural strengths for all shapes of sections are calculated based on their principal axes of bending. For the Rectangular, I-Shape, Box, Channel, Double Channel, Circular, Pipe, T-Shape, and Double Angle sections, the principal axes coincide with their geometric axes. For the Single Angle sections, the principal axes are determined and all computations except shear are based on that.

For *all* sections, the nominal shear strengths are calculated for directions aligned with the geometric axes, which typically coincide with the principal axes. Again, the exception is the Single Angle section.

If the user specifies nonzero nominal capacities for one or more of the members on the Steel Frame Overwrites form, those values will override the calculated values for those members. The specified capacities should be based on the principal axes of bending for flexure, and the geometric axes for shear.

3.5.1 Nominal Tensile Strength

This section applies to the members subject to axial tension.

Although there is no maximum slenderness limit for members designed to resist tension forces, the slenderness ratio preferably should not exceed 300 (AISC D1). A warning message to that effect is printed for such slender elements under tension.

The design tensile strength, $\phi_t P_n$, and the allowable tensile strength, P_n/Ω_t , of tension members is taken as the lower value obtained according to the limit

states of yielding of gross section under tension and tensile rupture in the net section.

3.5.1.1 Tensile Yielding in the Gross Section

$$P_n = F_y A_g \quad (\text{AISC D2-1})$$

$$\phi_t = 0.90 \text{ (LRFD)} \quad (\text{AISC D2})$$

$$\Omega_t = 1.67 \text{ (ASD)} \quad (\text{AISC D2})$$

3.5.1.2 Tensile Rupture in the Net Section

$$P_n = F_u A_e \quad (\text{AISC D2-2})$$

$$\phi_t = 0.75 \text{ (LRFD)} \quad (\text{AISC D2})$$

$$\Omega_t = 2.00 \text{ (ASD)} \quad (\text{AISC D2})$$

The effective net area, A_e , is assumed to be equal to the gross cross-sectional area, A_g , by default. For members that are connected with welds or members with holes, the A_e/A_g ratio must be modified using the steel frame design Overwrites to account for the effective area.

3.5.2 Nominal Compressive Strength

The design compressive strength, $\phi_c P_n$, and the allowable compressive strength, P_n/Ω_c , of members subject to axial compression are addressed in this section. The resistance and safety factors used in calculation of design and allowable compressive strengths are:

$$\phi_c = 0.90 \text{ (LRFD)} \quad (\text{AISC E1})$$

$$\Omega_c = 1.67 \text{ (ASD)} \quad (\text{AISC E1})$$

In the determination, the effective length factor K_2 is used as the K -factor. If the chosen analysis method in the Preferences is the General Second Order Elastic Analysis, the First Order Analysis using Amplified First Order Analysis, or the Limited First Order Analysis, the calculated K_2 factors are used. If the user overwrites the K_2 factors, the overwritten values are used. If the chosen analysis method is one of any Direct Analysis Methods, the effective

length factor, K , for calculation of P_n is taken as one (AISC App 7.1). The overwritten value of K_2 will have no effect for the latter case.

The nominal axial compressive strength, P_n , depends on the slenderness ratio, Kl/r , where

$$\frac{Kl}{r} = \max \left\{ \frac{K_{33}l_{33}}{r_{33}}, \frac{K_{22}l_{22}}{r_{22}} \right\}.$$

For all sections except Single Angles, the principal radii of gyration r_{22} and r_{33} are used. For Single Angles, the minimum (principal) radius of gyration, r_z , is used instead of r_{22} and r_{33} , conservatively, in computing Kl/r . K_{33} and K_{22} are two values of K_2 for the major and minor axes of bending.

Although there is no maximum slenderness limit for members designed to resist compression forces, the slenderness ratio preferably should not exceed 200 (AISC E2). A warning message to that effect is given for such slender elements under compression.

The members with any slender element and without any slender elements are handled separately.

The limit states of torsional and flexural-torsional buckling are ignored for closed sections (Box and Pipe sections), solid sections, general sections, and sections created using Section Designer.

3.5.2.1 Members without Slender Elements

The nominal compressive strength of members with compact and noncompact sections, P_n , is the minimum value obtained according to the limit states of flexural buckling, torsional and flexural-torsional buckling.

3.5.2.1.1 Flexural Buckling

For compression members with compact and noncompact sections, the nominal compressive strength, P_n , based on the limit state of flexural buckling, is given by

$$P_n = F_{cr}A_g. \quad (\text{AISC E3-1})$$

The flexural buckling stress, F_{cr} , is determined as follows:

$$F_{cr} = \begin{cases} \left(0.658 \frac{F_y}{F_e}\right) F_y, & \text{if } \frac{KL}{r} \leq 4.71 \sqrt{\frac{E}{F_y}}, \\ 0.877 F_e, & \text{if } \frac{KL}{r} > 4.71 \sqrt{\frac{E}{F_y}}, \end{cases} \quad (\text{AISC E3-2, E3-3})$$

where F_e is the elastic critical buckling stress given by

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}. \quad (\text{AISC E3-4})$$

3.5.2.1.2 Torsional and Flexural-Torsional Buckling

For compression members with compact and noncompact sections, the nominal compressive strength, P_n , based on the limit state of torsional and flexural-torsional buckling is given by

$$P_n = F_{cr} A_g \quad (\text{AISC E4-1})$$

where A_g is the gross area of the member. The flexural buckling stress, F_{cr} , is determined as follows.

3.5.2.1.2.1 *Box, Pipe, Circular, Rectangular, General and Section Designer Sections*

The limit states of torsional and flexural-torsional buckling are ignored for members with closed sections, such as Box and Pipe sections, solid sections (Circular and Rectangular), General sections and sections created using the Section Designer.

3.5.2.1.2.2 *Double Angle and T-Shapes*

$$F_{cr} = \left(\frac{F_{cr22} + F_{crz}}{2H}\right) \left[1 - \sqrt{1 - \frac{4F_{cr22}F_{crz}H}{(F_{cr22} + F_{crz})^2}}\right], \quad (\text{AISC E4-2})$$

where,

$$F_{cr22} = \begin{cases} (0.658^{\frac{F_y}{F_e}})F_y, & \text{if } \frac{KL_{22}}{r_{22}} \leq 4.71\sqrt{\frac{E}{F_y}}, \\ 0.877F_e, & \text{if } \frac{KL_{22}}{r_{22}} > 4.71\sqrt{\frac{E}{F_y}}, \end{cases} \quad (\text{AISC E3-2, E3-3})$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL_{22}}{r_{22}}\right)^2}, \quad \text{and} \quad (\text{AISC E3-4})$$

$$F_{crz} = \frac{GJ}{A_g \bar{r}_0^2}. \quad (\text{AISC E4-3})$$

3.5.2.1.2.3 I-Shape, Double Channel, Channel, Single Angle Sections

For I-Shape, Double Channel, Channel, and Single Angle sections, F_{cr} is calculated using the torsional or flexural-torsional elastic buckling stress, F_e , as follows:

$$F_{cr} = \begin{cases} \left(0.658^{\frac{F_y}{F_e}}\right)F_y, & \text{if } \frac{KL}{r} \leq 4.71\sqrt{\frac{E}{F_y}}, \\ 0.877F_e, & \text{if } \frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}. \end{cases} \quad (\text{AISC E3-2, E3-3, E-4b})$$

where F_e is calculated from the following equations:

3.5.2.1.2.3.1 I-Shapes and Double Channel Sections

$$F_e = \left[\frac{\pi^2 EC_w}{(K_z L_z)^2} + GJ \right] \left(\frac{1}{I_{22} + I_{33}} \right) \quad (\text{AISC E4-4})$$

3.5.2.1.2.3.2 Channel Sections

$$F_e = \left(\frac{F_{e33} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{e33}F_{ez}H}{(F_{e33} + F_{ez})^2}} \right] \quad (\text{AISC E4-5})$$

3.5.2.1.2.3.3 Single Angle Sections with Equal Legs

$$F_e = \left(\frac{F_{e33} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{e33}F_{ez}H}{(F_{e33} + F_{ez})^2}} \right] \quad (\text{AISC E4-5})$$

3.5.2.1.2.3.4 Single Angle Sections with Unequal Legs

F_e is the lowest root of the cubic equation.

$$(F_e - F_{e33})(F_e - F_{e22})(F_e - F_{ez}) - F_e^2 (F_e - F_{e22}) \left(\frac{x_o}{\bar{r}_o} \right)^2 - F_e^2 (F_e - F_{e33}) \left(\frac{y_o}{\bar{r}_o} \right) = 0 \quad (\text{AISC E4-6})$$

In the preceding equations,

C_w is the warping constant, in⁶ (mm⁶)

x_o, y_o are the coordinates of the shear center with respect to the centroid, $x_o = 0$ for Double Angle and T-Shaped members (y-axis symmetry)

$$\bar{r}_o = \sqrt{x_o^2 + y_o^2 + \frac{I_{22} + I_{33}}{A_g}} = \text{polar radius of gyration about the shear center} \quad (\text{AISC E4-7})$$

$$H = 1 - \left(\frac{x_o^2 + y_o^2}{\bar{r}^2} \right) \quad (\text{AISC E4-8})$$

$$F_{e33} = \frac{\pi^2 E}{(K_{33}L_{33}/r_{33})^2} \quad (\text{AISC E4-9})$$

$$F_{e22} = \frac{\pi^2 E}{(K_{22}L_{22}/r_{22})^2} \quad (\text{AISC E4-10})$$

$$F_{ez} = \left[\frac{\pi^2 EC_w}{(K_z L_z)^2} + GJ \right] \frac{1}{A\bar{r}_o^2} \quad (\text{AISC E 4-11})$$

K_{22}, K_{33} are effective length factors K_2 in minor and major directions

- K_z is the effective length factor for torsional buckling, and it is taken equal to K_{LTB} in this program; it can be overwritten
- L_{22}, L_{33} are effective lengths in the minor and major directions
- r_{22}, r_{33} are the radii of gyration about the principal axes
- L_z is the effective length for torsional buckling and it is taken equal to L_{22} by default, but it can be overwritten.

For angle sections, the principal moment of inertia and radii of gyration are used for computing F_e . Also, the maximum value of KL , i.e., $\max(K_{22}L_{22}, K_{33}L_{33})$, is used in place of $K_{22}L_{22}$ or $K_{33}L_{33}$ in calculating F_{e22} and F_{e33} in this case. The principal maximum value r_{\max} is used for calculating F_{e33} , and the principal minimum value r_{\min} is used in calculating F_{e22} .

3.5.2.2 Members with Slender Elements

The nominal compressive strength of members with slender sections, P_n , is the minimum value obtained according to the limit states of flexural, torsional and flexural-torsional buckling.

3.5.2.2.1 Flexural Buckling

For compression members with slender sections, the nominal compressive strength, P_n , based on the limit state of flexural buckling, is given by

$$P_n = F_{cr} A_g. \quad (\text{AISC E7-1})$$

The flexural buckling stress, F_{cr} , is determined as follows:

$$F_{cr} = \begin{cases} Q \left(0.658 \frac{QF_y}{F_e} \right) F_y, & \text{if } F_e \geq 0.44QF_y, \text{ and} \\ 0.877F_e, & \text{if } F_e < 0.44QF_y, \end{cases} \quad (\text{AISC E7-2, E7-3})$$

where F_e is the elastic critical buckling stress for flexural buckling limit state.

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}. \quad (\text{AISC E3-4})$$

3.5.2.2.2 Torsional and Flexural-Torsional Buckling

For compression members with slender sections, the nominal compressive strength, P_n , based on Torsional and Flexural-Torsional limit state is given by:

$$P_n = F_{cr} A_g, \text{ where} \quad (\text{AISC E7-1})$$

F_{cr} is determined as follows:

$$F_{cr} = \begin{cases} Q \left(0.658 \frac{QF_y}{F_e} \right) F_y & \text{if } F_y \geq 0.44QF_y, \text{ and} \\ 0.877F_e & \text{if } F_y < 0.44F_y, \end{cases} \quad (\text{AISC E7-2, E7-3})$$

where, F_e is the elastic critical buckling stress for torsional and flexural-torsional limit states, which are given for different shapes as follows.

3.5.2.2.2.1 Box, Pipe, Circular, Rectangular, General and Section Designer Sections

The limit states of torsional and flexural-torsional buckling are ignored for members with closed (Box and Pipe), solid (Circular and Rectangular), General sections and sections created using the Section Designer.

3.5.2.2.2.2 I-Shape and Double Channel Sections

$$F_e = \left[\frac{\pi^2 EC_w}{(K_2 L_2)^2} + GJ \right] \left(\frac{1}{I_{22} + I_{33}} \right) \quad (\text{AISC E7, E4-4})$$

3.5.2.2.2.3 Channel Sections

$$F_e = \left(\frac{F_{e33} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{e33}F_{ez}H}{(F_{e33} + F_{ez})^2}} \right] \quad (\text{AISC E7, E4-5})$$

3.5.2.2.2.4 Double Angle Sections *and T-Shapes*

$$F_e = \left(\frac{F_{e22} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{e22}F_{ez}H}{(F_{e33} + F_{ez})^2}} \right] \quad (\text{AISC E7, E4-5})$$

3.5.2.2.2.5 Single Angle Sections *with Equal Legs*

$$F_e = \left(\frac{F_{e33} + F_{ez}}{2H} \right) \left[1 - \sqrt{1 - \frac{4F_{e33}F_{ez}H}{(F_{e33} + F_{ez})^2}} \right] \quad (\text{AISC E7, E4-5})$$

3.5.2.2.2.6 Single Angle Sections *with Unequal Legs*

F_e is the lowest root of the cubic equation.

$$(F_e - F_{e33})(F_e - F_{e22})(F_e - F_{ez}) - F_e^2 (F_e - F_{e22}) \left(\frac{x_o}{\bar{r}_o} \right)^2 - F_e^2 (F_e - F_{e33}) \left(\frac{y_o}{\bar{r}_o} \right)^2 = 0 \quad (\text{AISC E7, E4-6})$$

The variables used in the preceding expressions for F_e , such as C_w , x_o , y_o , \bar{r}_o , H , F_{e33} , F_{e22} , F_{ez} , K_{22} , K_{33} , K_z , L_{22} , L_{33} , L_z , KL/r , and so on, were explained in the previous section.

3.5.2.2.3 Reduction Factor for Slenderness

The reduction factor for slender compression elements, Q , is computed as follows:

$$Q = Q_s Q_a, \quad (\text{AISC E7})$$

where Q_s and Q_a are reduction factors for slender unstiffened compression elements (flanges of I-Shapes, T-Shapes, Double Angles, Channels, and Double Channels; legs of angles; and stems of T-Shapes) and slender stiffened compression elements (webs of I-Shapes, Channels, and Boxes; and Pipe sections), respectively. For cross-sections composed of only unstiffened slender elements, $Q = Q_s$ ($Q_a = 1$) and for cross-sections composed of only stiffened slender elements, $Q = Q_a$ ($Q_s = 1$).

The reduction factor, Q_s , for slender unstiffened elements is defined as follows:

3.5.2.2.3.1 Flange of I-Shape, T-Shape, Channel and Double Channel Sections

Rolled:

$$Q_s = \begin{cases} 1.0, & \text{if } \frac{b}{t} \leq 0.56 \sqrt{\frac{E}{F_y}}, \\ 1.415 - 0.74 \left(\frac{b}{t} \right) \sqrt{\frac{F_y}{E}}, & \text{if } 0.56 \sqrt{\frac{E}{F_y}} < \frac{b}{t} \leq 1.03 \sqrt{\frac{E}{F_y}}, \text{ and} \\ \frac{0.69E}{F_y \left(\frac{b}{t} \right)^2}, & \text{if } \frac{b}{t} > 1.03 \sqrt{\frac{E}{F_y}}. \end{cases}$$

(AISC E7-4, E7-5, E7-6)

Built-Up:

$$Q_s = \begin{cases} 1.0, & \text{if } \frac{b}{t} \leq 0.64 \sqrt{\frac{Ek_c}{F_y}}, \\ 1.415 - 0.65 \left(\frac{b}{t} \right) \sqrt{\frac{F_y}{Ek_c}}, & \text{if } 0.64 \sqrt{\frac{Ek_c}{F_y}} < \frac{b}{t} \leq 1.17 \sqrt{\frac{Ek_c}{F_y}}, \\ \frac{0.90Ek_c}{F_y \left(\frac{b}{t} \right)^2}, & \text{if } \frac{b}{t} > 1.17 \sqrt{\frac{Ek_c}{F_y}}, \end{cases}$$

(AISC E7-7, E7-8, E7-9)

where $k_c = \frac{4}{\sqrt{h/t_w}}$ and $0.35 \leq k_c \leq 0.76$, (AISC E7.1b)

and b/t is defined as

$$\frac{b}{t} = \begin{cases} \left(\frac{b_t}{2t_f} \right) & \text{for I Shapes,} \\ \left(\frac{b_f}{2t_f} \right) & \text{for T Shapes,} \\ b_f/t_f & \text{for Channels,} \\ b_f/t_f & \text{for Double Channels.} \end{cases} \quad (\text{AISC B4.1a, E7.1})$$

3.5.2.2.3.1.1 Legs of Single and Double Angle Sections

$$Q_s = \begin{cases} 1.0, & \text{if } \frac{b}{t} \leq 0.45 \sqrt{\frac{E}{F_y}}, \\ 1.34 - 0.76 \left(\frac{b}{t} \right) \sqrt{\frac{F_y}{E}}, & \text{if } 0.45 \sqrt{\frac{E}{F_y}} < \frac{b}{t} \leq 0.91 \sqrt{\frac{E}{F_y}}, \text{ and} \\ \frac{0.53E}{F_y \left(\frac{b}{t} \right)^2}, & \text{if } \frac{b}{t} > 0.91 \sqrt{\frac{E}{F_y}}, \end{cases}$$

(AISC E7-10, E7-11, E7-12)

where b is the full width of the longest leg, and t is the corresponding thickness (AISC B4.1b, E7.1c).

3.5.2.2.3.1.2 Stem of T-Sections

$$Q_s = \begin{cases} 1.0, & \text{if } \frac{d}{t} \leq 0.75 \sqrt{\frac{E}{F_y}}, \\ 1.908 - 1.22 \sqrt{\frac{F_y}{E}}, & \text{if } 0.75 \sqrt{\frac{E}{F_y}} < \frac{d}{t} \leq 1.03 \sqrt{\frac{E}{F_y}}, \text{ and} \\ \frac{0.69E}{F_y \left(\frac{d}{t} \right)^2}, & \text{if } \frac{d}{t} > 1.03 \sqrt{\frac{E}{F_y}}, \end{cases}$$

(AISC E7-13, E7-14, E7-15)

where d is the full nominal depth of the tee and t is the thickness of the element (AISC B4.1d).

For T-Shapes, the Q_s is calculated for the flange and web separately, and the minimum of the two values is used as Q_s . For Angle and Double Angle sections, Q_s is calculated based on the leg that gives the largest b/t and so the smallest Q_s .

The reduction factor, Q_a , for slender stiffened elements is defined as follows:

$$Q_a = \frac{A_{eff}}{A}, \quad (\text{AISC E7-16})$$

where A is the total cross sectional area of the member, and A_{eff} is the summation of the effective areas of the cross-section,

$$A_{eff} = A - \sum (b - b_e)t,$$

based on the reduced effective width, b_e , which is determined as follows.

3.5.2.2.3.1.3 Webs of I-Shapes, Channels, and Double Channels

$$b_e = \begin{cases} 1.92t \sqrt{\frac{E}{f}} \left[1 - \frac{0.34}{(b/t)} \sqrt{\frac{E}{F}} \right] \leq b, & \text{if } \frac{b}{t} \geq 1.49 \sqrt{\frac{E}{f}}, \text{ and} \\ b, & \text{if } \frac{b}{t} < 1.49 \sqrt{\frac{E}{f}}, \end{cases} \quad (\text{AISC E7-17})$$

where f is taken as F_{cr} with $Q = 1.0$ (AISC 7.2a), and b is taken for rolled shapes as the clear distance between flanges less the corner radius, and is taken for welded shapes as the clear distance between flanges.

3.5.2.2.3.2 Webs and Flanges of Box Sections

$$b_e = \begin{cases} 1.92t \sqrt{\frac{E}{f}} \left[1 - \frac{0.38}{(b/t)} \sqrt{\frac{E}{F}} \right] \leq b, & \text{if } \frac{b}{t} \geq 1.40 \sqrt{\frac{E}{f}}, \text{ and} \\ b, & \text{if } \frac{b}{t} < 1.40 \sqrt{\frac{E}{F_y}}, \end{cases} \quad (\text{AISC E7-18})$$

where f is conservatively taken as F_y (AISC 7.2b). The flange, b , is taken as $b_f - 3t_w$, and for webs, b is taken as $h - 3t_f$ (AISC B4.1d). The design wall thickness is modified for the welding process (AISC B3.12)

3.5.2.2.3.3 Pipe Sections

The reduction factor for slender stiffened elements is given directly by:

$$Q_a = Q = \begin{cases} 1.0, & \text{if } D/t < 0.11 \frac{E}{F_y}, \\ \frac{0.038E}{F_y(D/t)} + \frac{2}{3}, & \text{if } 0.11 \frac{E}{F_y} < \frac{D}{t} < 0.45 \frac{E}{F_y}, \text{ and (AISC E7-19)} \\ 1.0, & \text{if } D/t > 0.45 \frac{E}{F_y}, \end{cases}$$

where D is the outside diameter and t is the wall thickness. The design wall thickness is modified for the welding process (AISC B3.12). If D/t exceeds $0.45 E/F_y$, the section is considered to be too slender and it is not designed.

3.5.3 Nominal Flexure Strength

This section applies to members subject to simple bending about one principal axis. The members are assumed to be loaded in a plane parallel to a principal axis that passes through the shear center, or restrained against twisting.

The design flexural strength, $\phi_b M_n$, and the allowable flexural strength, M_n/Ω_b , are determined using the following resistance and safety factors:

$$\phi_b = 0.90 \text{ (LRFD)} \quad \text{(AISC F1(1))}$$

$$\Omega_b = 1.67 \text{ (ASD)} \quad \text{(AISC F1(1))}$$

When determining the nominal flexural strength about the major principal axis for any sections for the limit state of lateral-torsional buckling, it is common to use the term C_b , the lateral-torsional buckling modification factor for non-uniform moment diagram. C_b is calculated as follows:

$$C_b = \frac{12.5M_{\max}}{2.5M_{\max} + 3M_A + 4M_B + 3M_c} R_m \leq 3.0, \quad \text{(AISC F1-1)}$$

where,

M_{\max} = absolute value of maximum moment in unbraced segment, kip-in. (N-mm)

M_A = absolute value of moment at quarter point of the unbraced segment, kip-in. (N-mm)

M_B = absolute value of moment at centerline of the unbraced segment, kip-in. (N-mm)

M_C = absolute value of moment at three-quarter point of the unbraced segment, kip-in. (N-mm)

R_m = cross-section monosymmetry parameter
 = 1.0, doubly symmetric members
 = 1.0, singly symmetric member subject to single curvature bending
 = $0.5 + 2 \left(\frac{I_{yc}}{I_y} \right)^2$, singly symmetric members subjected to reverse curvature bending

I_y = moment of inertia about the principal y-axis, in.⁴ (mm⁴)

I_{yc} = moment of inertia about y-axis referred to the compression flange, or if reverse curvature bending, referred to the smaller flange, in.⁴ (mm⁴)

$$R_m = \begin{cases} 1.0, & \text{for Double Channel, Box, Pipe, and} \\ & \text{doubly symmetric I Shapes,} \\ 1.0, & \text{for Channel, Tee, Double Angle and singly symmetric} \\ & \text{I Shapes subjected to curvature bending, and} \\ 0.5 + 2 \left(\frac{I_{yc}}{I_y} \right)^2, & \text{for Channel, Tee, Double Angle, and singly symmetric} \\ & \text{I Shapes subjected to reverse curvature bending.} \end{cases}$$

If the member is under tension and if the section is doubly symmetric, C_b is increased by a factor f_{cb} where R_a is given as follows:

$$R_a = \begin{cases} \sqrt{1 + \frac{P_u}{P_{ey}}} & \text{(LRFD)} \\ \sqrt{1 + \frac{1.5P_a}{P_{ey}}} & \text{(ASD)} \end{cases} \quad \text{(AISC H1.2)}$$

C_b should be taken as 1.0 for cantilevers. However, the program is unable to detect whether the member is a cantilever. **The user should overwrite C_b for**

cantilevers. The program also defaults C_b to 1.0 if the minor unbraced length, l_{22} , is redefined to be more than the length of the member by the user or the program, i.e., if the unbraced length is longer than the member length. The Overwrites can be used to change the value of C_b for any member.

The nominal bending strength depends on the following criteria: the geometric shape of the cross-section; the axis of bending; the compactness of the section; and a slenderness parameter for lateral-torsional buckling. The nominal bending strength is the minimum value obtained according to the limit states of yielding, lateral-torsional buckling, flange local buckling, web local buckling, tension flange yielding as appropriate to different structural shapes. The following sections describe how different members are designed against flexure in accordance with AISC Chapter F. AISC, in certain cases, gives options in the applicability of its code section, ranging from F2 to F12. In most cases, the program follows the path of the sections that gives more accurate results at the expense of more detailed calculation. In some cases, the program follows a simpler path. For an easy reference, Table 3-2 shows the AISC sections for the various scenarios.

Table 3.2 Selection Table for the Application of Chapter F Sections







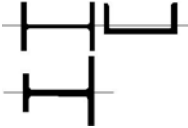
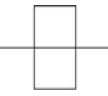
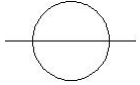



| Section in Chapter F | Cross Section | Flange Slenderness | Web Slenderness | Limit States |
|----------------------|---|--------------------|-----------------|------------------|
| F2 |  | C | C | Y, LTB |
| F3 |  | NC, S | C | LTB, FLB |
| F4 |  | C, NC, S | NC | Y, LTB, FLB |
| F5 |  | C, NC, S | S | Y, LTB, FLB |
| F4 |  | C, NC, S | C, NC | Y, LTB, FLB, TFY |

Table 3.2 Selection Table for the Application of Chapter F Sections

| Section in Chapter F | Cross Section | Flange Slenderness | Web Slenderness | Limit States |
|----------------------|---|--------------------|-----------------|------------------|
| F5 |  | C, NC, S | S | Y, LTB, FLB, TFY |
| F6 |  | C, NC, S | Any | Y, FLB |
| F7 |  | C, NC, S | C, NC | Y, FLB, WLB |
| F8 |  | N/A | N/A | Y, LB |
| F9 |  | C, NC, S | Any | Y, LTB, FLB |
| F10 |  | N/A | N/A | Y, LTB, LLB |
| F11 |  | N/A | Any | Y, LTB |
| F12 | Unsymmetrical shapes | N/A | N/A | All limit states |

Y = yielding

LTB = lateral-torsional buckling

FLB = flange local buckling

WLB = web local buckling

TFY = tension flange yielding

LLB = leg local buckling

LB = local buckling

C = compact or seismically compact

NC = noncompact

S = slender

3.5.3.1 Doubly Symmetric I-Sections

3.5.3.1.1 Major Axis Bending

The nominal flexural strength for major axis bending depends on compactness of the web and flanges.

3.5.3.1.1.1 Compact Webs with Compact Flanges

The nominal flexural strength is the lowest value obtained according to the limit states of yielding (plastic moment) and lateral-torsional buckling.

3.5.3.1.1.1 Yielding

$$M_n = M_p = F_y Z_{33}, \quad (\text{AISC F2-1})$$

where, Z_{33} is the plastic section modulus about the major axis.

3.5.3.1.1.2 Lateral-Torsional Buckling

$$M_n = \begin{cases} M_p, & \text{if } L_b \leq L_p, \\ C_b \left[M_p - (M_p - 0.7F_y S_{33}) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq M_p, & \text{if } L_p < L_b < L_r, \text{ and} \\ F_{cr} S_{33} \leq M_p, & \text{if } L_p > L_r, \end{cases}$$

(AISC F2-1, F2-2, F2-3)

where, S_{33} is the elastic section modulus taken about the major axis, L_b is the unbraced length, L_p and L_r are limiting lengths, and F_{cr} is the critical buckling stress. F_{cr} , L_p , and L_r are given by:

$$F_{cr} = \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_{ts}} \right)^2} \sqrt{1 + 0.078 \frac{Jc}{S_{33} h_0} \left(\frac{L_b}{r_{ts}} \right)^2}, \quad (\text{AISC F2-4})$$

$$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}}, \quad (\text{AISC F2-5})$$

$$L_r = 1.95 r_{ts} \frac{E}{0.7F_y} \sqrt{\frac{Jc}{S_{33} h_0}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{0.7F_y S_{33} h_0}{E Jc} \right)^2}}, \quad (\text{AISC F2-6})$$

where,

$$r_{ts}^2 = \frac{\sqrt{I_y C_w}}{S_{33}}, \quad (\text{AISC F2-7})$$

$$c = 1, \text{ and} \quad (\text{AISC F2-8a})$$

h_0 is the distance between flange centroids.

3.5.3.1.1.2 Compact Webs with Noncompact or Slender Flanges

The nominal flexural strength is the lowest value obtained from the limit states of lateral-torsional buckling and compression flange local buckling.

3.5.3.1.1.2.1 Lateral-Torsional Buckling

The provisions of lateral-torsional buckling for "Compact Web and Flanges" as described in the provision pages also apply to the nominal flexural strength of I-Shapes with compact webs and noncompact or slender flanges bent about their major axis.

$$M_n = \begin{cases} M_p, & \text{if } L_b \leq L_p, \\ C_b \left[M_p - (M_p - 0.7F_y S_{33}) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq M_p, & \text{if } L_p < L_b < L_r, \text{ and} \\ F_{cr} S_{33} \leq M_p, & \text{if } L_p > L_r. \end{cases}$$

(AISC F3.1, F2-1, F2-2, F2-3)

3.5.3.1.1.2.2 Compression Flange Local Buckling

$$M_n = \begin{cases} M_p - (M_p - 0.7F_y S_{33}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges,} \\ \frac{0.9E k_c S_{33}}{\lambda^2}, & \text{for slender flanges,} \end{cases}$$

(AISC F3-1, 3-2)

where λ , λ_{pf} , and λ_{rf} are the slenderness and limiting slenderness for compact and noncompact flanges from Table 3.5, respectively,

$$\lambda = \frac{b_f}{2t_f},$$

$$\lambda_{pf} = 0.38 \sqrt{\frac{E}{F_y}},$$

(AISC Table B4.1, F3.2)

$$\lambda_{rf} = \begin{cases} 1.0 \sqrt{\frac{E}{F_y}} & \text{(Rolled),} \\ 0.95 \sqrt{\frac{k_c E}{F_L}} & \text{(Welded),} \end{cases} \quad \text{(AISC Table B4.1, F3.2)}$$

and k_c is given by

$$k_c = \frac{4}{\sqrt{h/t_w}}, \quad 0.35 \leq k_c \leq 0.76. \quad \text{(AISC F.3.2)}$$

3.5.3.1.1.3 Noncompact Webs with Compact, Noncompact and Slender Flanges

The nominal flexural strength is the lowest values obtained from the limit states of compression flange yielding, lateral-torsional buckling, and compression flange local buckling.

3.5.3.1.1.3.1 Compression Flange Yielding

$$M_n = R_{pc} M_y, \quad \text{(AISC F4-1)}$$

where, R_{pc} is the web plasticity factor, which is determined as follows:

$$R_{pc} = \begin{cases} \frac{M_p}{M_y}, & \text{if } \lambda \leq \lambda_{pw}, \\ \left[\frac{M_p}{M_y} - \left(\frac{M_p}{M_y} - 1 \right) \left(\frac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}} \right) \right] \leq \frac{M_p}{M_y}, & \text{if } \lambda_{pw} < \lambda_w \leq \lambda_{rw}, \end{cases} \quad \text{(AISC F4-9a, F4-9b)}$$

where,

$$M_p = Z_{33} F_y \leq 1.6 S_{33} F_y \quad \text{(AISC F4-2)}$$

S_{33} = elastic section modulus for major axis bending

$$\lambda_w = \frac{h_c}{t_w} \quad \text{(AISC F4.2, Table B4.1)}$$

$\lambda_{pw} = \lambda_p$, the limiting slenderness for a compact web, as given in
Table 3-5 (AISC Table B4.1)

$\lambda_{rw} = \lambda_r$, the limiting slenderness for a noncompact web, as given in Table 3-5 (AISC Table B4.1)

and M_y is the yield moment, which is determined as follows:

$$M_y = S_{33}F_y \quad (\text{AISC F4-1})$$

3.5.3.1.1.3.2 Lateral-Torsional Buckling

$$M_n = \begin{cases} R_{pc}M_y, & \text{if } L_b \leq L_p, \\ C_b \left[R_{pc}M_y - (R_{pc}M_y - F_L S_{33}) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq R_{pc}M_y, & \text{if } L_p < L_b \leq L_r, \\ F_{cr} S_{33} \leq R_{pc}M_y, & \text{if } L_b > L_r, \end{cases} \quad (\text{AISC F4-1, F4-2, F4-3})$$

where,

$$F_{cr} = \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_t} \right)^2} \sqrt{1 + 0.078 \frac{J_c}{S_{33} h_o} \left(\frac{L_b}{r_t} \right)^2} \quad (\text{AISC F4-5})$$

$$r_t = \frac{b_f}{\sqrt{12 \left(\frac{h_o}{d} + \frac{1}{6} a_w \frac{h^2}{h_o d} \right)}} \quad (\text{AISC F4-10})$$

$$a_w = \frac{h_c t_w}{b_f t_f} \leq 10 \quad (\text{AISC F4-11})$$

$$C = \begin{cases} 1, & \text{if } I_{yc}/I_y > 0.23 \\ 0, & \text{if } I_{yc}/I_y \leq 0.23 \end{cases} \quad (\text{AISC F4.2})$$

$$L_p = 1.1 r_t \sqrt{\frac{E}{F_y}} \quad (\text{AISC F4-7})$$

$$L_r = 1.95 r_t \frac{E}{F_L} \sqrt{\frac{J}{S_{33} h_o}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{F_L S_{33} h_o}{E J} \right)^2}} \quad (\text{AISC F4-8})$$

$$F_L = 0.7F_y \quad (\text{AISC F4-6a})$$

R_{pc} = web plastification factor, which is determined using a formula describe previously (AISC F4-9)

I_{yc} = moment of inertia of the compression flange about the minor axis

I_y = moment of inertia of the entire section about the minor axis.

3.5.3.1.1.3.3 Compression Flange Local Buckling

$$M_n = \begin{cases} R_{pc}M_y, & \text{if flanges are compact,} \\ \left[R_{pc}M_y - (R_{pc}M_y - F_L S_{33}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right) \right], & \text{if flanges are noncompact, and} \\ \frac{0.9Ek_c S_{33}}{\lambda^2}, & \text{if flanges are slender,} \end{cases}$$

(AISC F4-1, F4-12, F4-13)

where,

$$F_L = 0.7F_y \quad (\text{AISC F4-6a, F4.3})$$

R_{pc} = is the web plastification factor, which is determined using a formula described previously (AISC F4-9, F4.3)

$$k_c = \frac{4}{\sqrt{h/t_w}}, \quad 35 \leq k_c \leq 0.76 \quad (\text{AISC F4.3, Table B4.1})$$

$$\lambda = \frac{b_f}{2t_f}$$

λ_{pf} = λ_p , the limiting slenderness for compact flange, as given in Table 3-5 (AISC Table B4.1, B4.3)

λ_{rf} = λ_r , the limiting slenderness for noncompact flange, as given in Table 3-5 (AISC Table B4.1, B4.3).

3.5.3.1.1.4 Slender Webs with Compact, Noncompact, and Slender Flanges

The nominal flexural strength is the lowest value obtained from the limit states of compression flange yielding, lateral-torsional buckling, and compression flange local buckling.

3.5.3.1.1.4.1 Compression Flange Yielding

$$M_n = R_{pg} F_y S_{33}, \quad (\text{AISC F5-1})$$

where R_{pg} is the bending strength reduction factor given by

$$R_{pg} = 1 - \frac{a_w}{1200 + 300a_w} \left(\frac{h_c}{t_w} - 5.7 \sqrt{\frac{E}{F_y}} \right) \leq 1.0, \quad (\text{AISC F5-6})$$

$$a_w = \frac{ht_w}{b_f t_f} \leq 10, \quad (\text{AISC F5.2, F4-11})$$

where h_0 is the distance between flange centroids (AISC F2.2).

3.5.3.1.1.4.2 Lateral-Torsional Buckling

$$M_n = R_{pg} F_{cr} S_{33}, \quad (\text{AISC F5-2})$$

where F_{cr} is the critical lateral-torsional buckling stress given by

$$F_{cr} = \begin{cases} F_y, & \text{if } L_b \leq L_p, \\ C_b \left[F_y - (0.3F_y) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq F_y, & \text{if } L_p < L_b \leq L_r, \text{ and} \\ \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_t} \right)^2} \leq F_y, & \text{if } L_p > L_r, \end{cases}$$

(AISC F5-1, F5-3, 5-4)

where,

$$L_p = 1.1r_t \sqrt{\frac{E}{F_y}} \quad (\text{AISC F5.2, 4-7})$$

$$L_r = \pi r_t \sqrt{\frac{E}{0.7F_y}} \quad (\text{AISC F5-5})$$

$$r_t = \frac{b_f}{\sqrt{12 \left(\frac{h_0}{d} + \frac{1}{6} a_w \frac{h^2}{h_0 d} \right)}} \quad (\text{AISC F5.2, F4-10})$$

R_{pg} is the bending strength reduction factor, which has been described in the previous section.

3.5.3.1.1.4.3 Compression Flange Local Buckling

$$M_n = R_{pg} F_{cr} S_{33}, \quad (\text{AISC F5-7})$$

where F_{cr} is the critical buckling stress given by

$$F_{cr} = \begin{cases} F_y, & \text{if flanges are compact,} \\ \left[F_y - (0.3F_y) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right) \right], & \text{if flanges are noncompact, and} \\ \frac{0.9Ek_c}{\left(\frac{b_f}{2t_f} \right)^2} \leq F_y, & \text{if flanges are slender,} \end{cases}$$

(AISC F5-1, F5-8, F5-9)

and λ , λ_{pf} , and λ_{rf} are the slenderness and the limiting slenderness ratios for compact and noncompact flanges from Table 3.5, respectively, and k_c is given by

$$k_c = \frac{4}{\sqrt{h/t_w}} \quad \text{where } 0.35 \leq k_c \leq 0.76. \quad (\text{AISC 5.3})$$

3.5.3.1.2 Minor Axis Bending

The nominal flexural strength is the lower value obtained according to the limit states of yielding (plastic moment) and flange local buckling.

3.5.3.1.2.1 Yielding

$$M_n = M_p = F_y Z_{22} \leq 1.6 F_y S_{22}, \quad (\text{AISC F6-1})$$

where S_{22} and Z_{22} are the section and plastic moduli about the minor axis, respectively.

3.5.3.1.2.2 Flange Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact flange,} \\ M_p - (M_p - 0.7 F_y S_{22}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ F_{cr} S_{22}, & \text{for slender flanges,} \end{cases} \quad (\text{AISC F6-1, F6-2, F6-3})$$

where,

$$F_{cr} = \frac{0.69E}{\lambda^2} \quad (\text{AISC 6-4})$$

$$\lambda = \frac{b_f}{2t_f} \quad (\text{AISC F6.2})$$

and λ_{pf} and λ_{rf} are the limiting slendernesses for compact and noncompact flanges, respectively, as described in Table 3-5 (AISC B4.1).

3.5.3.2 Singly Symmetric I-Sections

3.5.3.2.1 Major Axis Bending

The nominal of flexural strength for major axes bending depends on compactness of the web and flanges.

3.5.3.2.1.1 Compact and Noncompact Webs with Compact, Noncompact and Slender Flanges

The nominal flexural strength is the lowest values obtained from the limit sates of compression flange yielding, lateral-torsional buckling, compression flange local buckling, and tension flange yielding.

3.5.3.2.1.2 Compression Flange Yielding

$$M_n = R_{pc}M_{yc}, \quad (\text{AISC F4-1})$$

where, R_{pc} is the web plasticity factor, which is determined as follows:

$$R_{pc} = \begin{cases} \frac{M_p}{M_{yc}}, & \text{if } \lambda \leq \lambda_{pw}, \\ \left[\frac{M_p}{M_{yc}} - \left(\frac{M_p}{M_{yc}} - 1 \right) \left(\frac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}} \right) \right] \leq \frac{M_p}{M_{yc}}, & \text{if } \lambda_{pw} < \lambda_w \leq \lambda_{rw}, \end{cases}$$

(AISC F4-9a, F4-9b)

where,

$$M_p = Z_{33c}F_y \leq 1.6S_{33c}F_y \quad (\text{AISC F4-2})$$

S_{33c} = elastic section modulus for major axis bending referred to compression flange

S_{33t} = elastic section modulus for major axis bending referred to tension flange

$$\lambda = \frac{h_c}{t_w} \quad (\text{AISC F4.2, Table B4.1})$$

λ_{pw} = λ_p , the limiting slenderness for a compact web, as given in Table 3-5 (AISC Table B4.1)

λ_{rw} = λ_r , the limiting slenderness for a noncompact web, as given in Table 3-5 (AISC Table B4.1)

and M_{yc} is the yield moment for compression flange yielding, which is determined as follows:

$$M_{yc} = S_{33c}F_y. \quad (\text{AISC F4-1})$$

3.5.3.2.1.3 Lateral-Torsional Buckling

$$M_n = \begin{cases} R_{pc} M_{yc}, & \text{if } L_b \leq L_p, \\ C_b \left[R_{pc} M_{yc} - (R_{pc} M_{yc} - F_L S_{33c}) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq R_{pc} M_{yc}, & \text{if } L_p < L_b \leq L_r, \\ F_{cr} S_{33c} \leq R_{pc} M_{yc}, & \text{if } L_b > L_r, \end{cases}$$

(AISC F4-1, F4-2, F4-3)

where,

$$F_{cr} = \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_t} \right)^2} \sqrt{1 + 0.078 \frac{J_c}{S_{33} h_o} \left(\frac{L_b}{r_t} \right)^2} \quad (\text{AISC F4-5})$$

$$r_t = \frac{b_{fc}}{\sqrt{12 \left(\frac{h_o}{d} + \frac{1}{6} a_w \frac{h^2}{h_o d} \right)}} \quad (\text{AISC F4-10})$$

$$a_w = \frac{h_c t_w}{b_{fe} t_{fc}} \leq 10 \quad (\text{AISC F4-11})$$

$$C = \begin{cases} 1, & \text{if } I_{yc}/I_y > 0.23 \\ 0, & \text{if } I_{yc}/I_y \leq 0.23 \end{cases} \quad (\text{AISC F4.2})$$

$$L_p = 1.1 r_t \sqrt{\frac{E}{F_y}} \quad (\text{AISC F4-7})$$

$$L_r = 1.95 r_t \frac{E}{F_L} \sqrt{\frac{J}{S_{33} h_o}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{F_L S_{33c} h_o}{E J} \right)^2}} \quad (\text{AISC F4-8})$$

$$F_L = \begin{cases} 0.7 F_y, & \text{if } \frac{S_{33t}}{S_{33c}} \geq 0.7 \\ \frac{S_{33t}}{S_{33c}} F_y \geq 0.5 F_y, & \text{if } \frac{S_{33t}}{S_{33c}} \leq 0.7 \end{cases} \quad (\text{AISC F4-6a, F4-6b})$$

R_{pc} = web plastification factor, which is determined using a formula describe previously (AISC F4-9)

I_{yc} = moment of inertia of the compression flange about the minor axis

I_y = moment of inertia of the section about the minor axis.

3.5.3.2.1.4 Compression Flange Local Buckling

$$M_n = \begin{cases} R_{pc}M_{yc}, & \text{if flanges are compact,} \\ \left[R_{pc}M_{yc} - (R_{pc}M_{yc} - F_L S_{33c}) \left(\frac{\lambda - \lambda_{pt}}{\lambda_{rf} - \lambda_{pt}} \right) \right], & \text{if flanges are noncompact, and} \\ \frac{0.9Ek_c S_{33c}}{\lambda^2}, & \text{if flanges are slender,} \end{cases}$$

(AISC F4-1, F4-12, F4-13)

where,

F_L = is a calculated stress, which has been defined previously
(AISC F4-6a, F4-6b, F4.3)

R_{pc} = is the web plastification factor, which is determined using a formula described previously (AISC F4-9, F4.3)

$k_c = \frac{4}{\sqrt{h/t_w}}$, $35 \leq k_c \leq 0.76$ (AISC F4.3, Table B4.1)

$\lambda = \frac{b_{fc}}{2t_{fc}}$

$\lambda_{pf} = \lambda_p$, the limiting slenderness for compact flange, as given in Table 3-5 (AISC Table B4.1, B4.3)

$\lambda_{rf} = \lambda_r$, the limiting slenderness for noncompact flange, as given in Table 3-5 (AISC Table B4.1, B4.3).

3.5.3.2.1.5 Tension Flange Yielding

$$M_n = \begin{cases} M_p, & \text{if } S_{33t} \geq S_{33c} \\ R_{pt}M_{yt}, & \text{if } S_{33t} < S_{33c} \end{cases}$$

(AISC F4-14)

where, R_{pt} is the web plastification factor corresponding to the tension flange yielding limit state. It is determined as follows:

$$R_{pt} = \begin{cases} \frac{M_p}{M_{yt}}, & \text{if } \lambda \leq \lambda_{pw} \\ \frac{M_p}{M_{yt}} - \left(\frac{M_p}{M_{yt}} - 1 \right) \left(\frac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}} \right), & \text{if } \lambda_{pw} < \lambda \leq \lambda_{rw} \end{cases}$$

(AISC F4-15a, F4-15b)

where,

$$M_p = Z_{33}F_y \quad (\text{AISC F4-2})$$

S_{33c} = elastic section modulus for major axis bending referred to compression flange

S_{33t} = elastic section modulus for major axis bending referred to tension flange

$$\lambda_w = \frac{h_c}{t_w} \quad (\text{AISC F4.2, Table B4.1})$$

λ_{wp} = λ_p , the limiting slenderness for a compact web, as given in Table 3-5 (AISC Table B4.1)

λ_{rw} = λ_r , the limiting slenderness for a noncompact web, as given in Table 3-5. (AISC Table B4.1)

3.5.3.2.1.6 *Slender Webs with Compact, Noncompact and Slender Flanges*

The nominal flexural strength is the lowest value obtained from the limit states of compression flange yielding, lateral-torsional buckling, compression flange local buckling, and tension flange yielding.

3.5.3.2.1.6.1 Compression Flange Yielding

$$M_n = R_{pg}F_yS_{33c}, \quad (\text{AISC F5-1})$$

where, R_{pg} is the bending strength reduction factor given by

$$R_{pg} = 1 - \frac{a_w}{1200 + 300a_w} \left(\frac{h_c}{t_w} - 5.7 \sqrt{\frac{E}{F_y}} \right) \leq 1.0 \quad (\text{AISC F5-6})$$

$$a_w = \frac{ht_w}{b_f t_f} \leq 10 \quad (\text{AISC F5.2, F4-11})$$

where, h_0 is the distance between flange centroids (AISC F2.2).

3.5.3.2.1.6.2 Lateral-Torsional Buckling

$$M_n = R_{pg} F_{cr} S_{33c}, \quad (\text{AISC F5-2})$$

where, F_{cr} is the critical lateral-torsional buckling stress given by

$$F_{cr} = \begin{cases} F_y, & \text{if } L_b \leq L_p, \\ C_b \left[F_y - (0.3F_y) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq F_y, & \text{if } L_p < L_b \leq L_r, \text{ and} \\ \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_t} \right)^2} \leq F_y, & \text{if } L_b > L_r, \end{cases} \quad (\text{AISC F5-1, F5-3, 5-4})$$

where,

$$L_p = 1.1 r_t \sqrt{\frac{E}{F_y}} \quad (\text{AISC F5.2, 4-7})$$

$$L_r = \pi r_t \sqrt{\frac{E}{0.7F_y}} \quad (\text{AISC F5-5})$$

$$r_t = \frac{b_{fc}}{\sqrt{12 \left(\frac{h_0}{d} + \frac{1}{6} a_w \frac{h^2}{h_0 d} \right)}} \quad (\text{AISC F5.2, F4-10})$$

R_{pg} is the bending strength reduction factor, which has been described in a previous section.

3.5.3.2.1.6.3 Compression Flange Local Buckling

$$M_n = R_{pg} F_{cr} S_{33c}, \quad (\text{AISC F5-7})$$

where, F_{cr} is the critical buckling stress given by

$$F_{cr} = \begin{cases} F_y, & \text{if flanges are compact,} \\ \left[F_y - (0.3 F_y) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right) \right], & \text{if flanges are noncompact, and} \\ \frac{0.9 E k_c}{\left(\frac{b_{fc}}{2 t_{fc}} \right)^2} \leq F_y, & \text{if flanges are slender,} \end{cases}$$

(AISC F5-1, F5-8, F-9)

and λ , λ_{pf} , and λ_{rf} are the slenderness and the limiting slenderness ratios for compact and noncompact flanges from Table 3.5, respectively, and k_c is given by

$$k_c = \frac{4}{\sqrt{h/t_w}}, \quad \text{where } 0.35 \leq k_c \leq 0.76. \quad (\text{AISC 5.3})$$

3.5.3.2.1.6.4 Tension Flange Yielding

$$M_n = \begin{cases} M_p & \text{if } S_{33t} \geq S_{33c}, \\ F_y S_{33t} & \text{if } S_{33t} < S_{33c}. \end{cases} \quad (\text{AISC F5-10})$$

3.5.3.2.2 Minor Axis Bending

The nominal flexural strength is the lower value obtained according to the limit states of yielding (plastic moment) and flange local buckling.

3.5.3.2.2.1 Yielding

$$M_n = M_p = F_y Z_{22} \leq 1.6 F_y S_{22}, \quad (\text{AISC F6-1})$$

where, S_{22} and Z_{22} are the section and plastic moduli about the minor axis, respectively.

3.5.3.2.2 Flange Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact flange,} \\ M_p - (M_p - 0.7F_y S_{22}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ F_{cr} S_{22}, & \text{for slender flanges,} \end{cases} \quad (\text{AISC F6-1, F6-2, F6-3})$$

where,

$$F_{cr} = \frac{0.69E}{\lambda^2} \quad (\text{AISC 6-4})$$

$$\lambda = \max \left\{ \frac{b_{fb}}{t_{fb}}, \frac{b_{ft}}{t_{ft}} \right\} \quad (\text{AISC F6.2})$$

and λ_{pf} and λ_{rf} are the limiting slendernesses for compact and noncompact flanges, respectively, as described in Table 3-5 (AISC B4.1).

3.5.3.3 Channel and Double Channel Sections

3.5.3.3.1 Major Axis Bending

The nominal flexural strength is the lowest value obtained according to the limit states of yielding (plastic moment), lateral-torsional buckling, and compression flange local buckling.

3.5.3.3.1.1 Yielding

$$M_n = M_p = F_y Z_{33}, \quad (\text{AISC F2-1})$$

where Z_{33} is the plastic section modulus about the major axis.

3.5.3.3.1.2 Lateral-Torsional Buckling

$$M_n = \begin{cases} M_p, & \text{if } L_b \leq L_p, \\ C_b \left[M_p - (M_p - 0.7F_y S_{33}) \left(\frac{L_b - L_p}{L_r - L_p} \right) \right] \leq M_p & \text{if } L_p < L_b < L_r, \text{ and} \\ F_{cr} S_{33} \leq M_p, & \text{if } L_p > L_r, \end{cases}$$

(AISC F2-1, F2-2, F2-3)

where S_{33} is the elastic section modulus taken about the major axis, L_b is the unbraced length, L_p and L_r are limiting lengths, and F_{cr} is the critical buckling stress. F_{cr} , L_p and L_r are given by

$$F_{cr} = \frac{C_b \pi^2 E}{\left(\frac{L_b}{r_{ts}} \right)^2} \sqrt{1 + 0.078 \frac{Jc}{S_{33} h_0} \left(\frac{L_b}{r_{ts}} \right)^2} \quad (\text{AISC F2-4})$$

$$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}} \quad (\text{AISC F2-5})$$

$$L_r = 1.95 r_{ts} \frac{E}{0.7 F_y} \sqrt{\frac{Jc}{S_{33} h_0}} \sqrt{1 + \sqrt{1 + 6.76 \left(\frac{0.7 F_y S_{33} h_0}{E Jc} \right)^2}} \quad (\text{AISC F2-6})$$

where

$$r_{ts}^2 = \frac{\sqrt{I_y C_w}}{S_{33}} \quad (\text{AISC F2-7})$$

$$C = \begin{cases} 1 & \text{for Double Channel sections} \\ \frac{h_o}{2} \sqrt{\frac{I_y}{C_w}} & \text{for Channel sections} \end{cases} \quad (\text{AISC F2-8a, F2-8b})$$

and h_o is the distance between flange centroids.

3.5.3.3.1.3 Compression Flange Local Buckling

The nominal strength for compression flange local buckling is determined based on whether the web is compact, noncompact, or slender.

If the web is compact,

$$M_n = \begin{cases} M_p, & \text{for compact flanges,} \\ M_p - (M_p - 0.7F_y S_{33}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ \frac{0.9Ek_c S_{33}}{\lambda^2}, & \text{for slender flanges,} \end{cases}$$

(AISC F2-1, F3-1, F3-2)

if the web is noncompact,

$$M_n = \begin{cases} R_{pc} M_y, & \text{for compact flange,} \\ R_{pc} M_y - (R_{pc} M_y - F_L S_{33}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ \frac{0.9Ek_c S_{33}}{\lambda^2}, & \text{for slender flanges,} \end{cases}$$

(AISC F4-1, F4-12, F4-13)

and if the web is slender,

$$M_n = R_{pg} F_{cr} S_{33} \quad (\text{AISC F5-7})$$

where, F_{cr} is the critical buckling stress give by

$$F_{cr} = \begin{cases} F_y, & \text{if flanges are compact,} \\ F_y - (0.3F_y) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{if the flanges are noncompact,} \\ \frac{0.9Ek_c}{\lambda^2} \leq F_y, & \text{if the flanges are slender,} \end{cases}$$

where,

$$\lambda = \frac{b_f}{2t_f}$$

λ_{pf} = λ_p , the limiting slenderness for compact flange, as given in Table 3-5 (AISC Table B4.1, B4.3)

λ_{rf} = λ_r , the limiting slenderness for noncompact flange, as given in Table 3-5 (AISC Table B4.1, B4.3)

$$k_c = \frac{4}{\sqrt{h/t_w}}, \quad 35 \leq k_c \leq 0.76 \quad (\text{AISC F4.3, Table B4.1})$$

$$F_L = 0.7F_y \quad (\text{AISC F4-6a, F4.3})$$

$$R_{pc} = \begin{cases} \frac{M_p}{M_y}, & \text{if } \lambda_w \leq \lambda_{pw} \\ \left[\frac{M_p}{M_y} - \left(\frac{M_p}{M_y} - 1 \right) \left(\frac{\lambda - \lambda_{pw}}{\lambda_{rw} - \lambda_{pw}} \right) \right] \leq \frac{M_p}{M_y}, & \text{if } \lambda_{pw} < \lambda_w \leq \lambda_{rw} \end{cases}$$

(AISC F4-9a, F4-9b)

$$R_{pg} = 1 - \frac{a_w}{1200 + 300a_w} \left(\frac{h_c}{t_w} - 5.7 \sqrt{\frac{E}{F_y}} \right) \leq 1.0 \quad (\text{AISC F5-6})$$

S_{33} = elastic section modulus for major axis bending,

$$\lambda_w = \frac{h_c}{t_w}$$

λ_{pw} = λ_p , the limiting slenderness for compact web, as given in Table 3-5 (AISC Table B4.1)

λ_{rw} = λ_r , the limiting slenderness for a noncompact web, as given in Table 3-5 (AISC Table B4.1)

R_{pg} is the bending strength reduction factor, which has been described in a previous section.

3.5.3.3.2 Minor Axis Bending

The nominal flexural strength is the lower value obtained according to the limit states of yielding (plastic moment) and flange local buckling.

3.5.3.3.2.1 Yielding

$$M_n = M_p = F_y Z_{22} \leq 1.6 F_y S_{22} \quad (\text{AISC F6-1})$$

where, S_{22} and Z_{22} are the section and plastic moduli about the minor axis, respectively.

3.5.3.3.2.2 Flange Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact flange,} \\ M_p - \left(M_p - 0.7 F_y S_{22} \right) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ F_{cr} S_{22}, & \text{for slender flanges,} \end{cases} \quad (\text{AISC F6-1, F6-2, F6-3})$$

where,

$$F_{cr} = \frac{0.69 E}{\lambda^2} \quad (\text{AISC 6-4})$$

$$\lambda = \frac{b_f}{2 t_f} \quad (\text{AISC F6.2})$$

and λ_{pf} and λ_{rf} are the limiting slendernesses for compact and noncompact flanges, respectively, as described in Table 3-5 (AISC B4.1).

3.5.3.4 Box Sections

This section applies to Box sections with compact or noncompact webs and compact, noncompact or slender flanges, bent about either axis. The program uses the same set of formulas for both major and minor direction bending, but with appropriate parameters.

The nominal flexural strength is the lowest value obtained according to the limit states of yielding (plastic moment), flange local buckling and web local buckling.

3.5.3.4.1 Yielding

$$M_n = M_p = F_y Z, \quad (\text{AISC F7-1})$$

where, Z is the plastic section modulus about the axis of bending.

3.5.3.4.2 Flange Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact flanges,} \\ M_p - (M_p - F_y S) \left(3.57 \frac{b}{t} \sqrt{\frac{F_y}{E}} - 4.0 \right) \leq M_p, & \text{for noncompact flanges, and} \\ F_y S_{eff}, & \text{for slender flanges,} \end{cases} \quad (\text{AISC F7-1, F7-2, F7-3})$$

where, S_{eff} is the effective section modulus determined using the effective compressive flange width, b_e ,

$$b_e = 1.92t \sqrt{\frac{E}{F_y}} \left[1 - \frac{0.38}{b/t} \sqrt{\frac{E}{F_y}} \right] \leq b. \quad (\text{AISC F7-4})$$

See the "Reduction Factor for Slenderness" section for details (AISC F7, E7.2).

3.5.3.4.3 Web Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact webs, and} \\ M_p - (M_p - F_y S_{33}) \left(0.305 \frac{h}{t_w} \sqrt{\frac{F_y}{E}} - 0.738 \right) \leq M_p, & \text{for noncompact webs,} \\ M_p - (M_p - F_y S_{33}) \left(0.305 \frac{h}{t_w} \sqrt{\frac{F_y}{E}} - 0.738 \right) \leq M_p, & \text{for slender webs.} \end{cases} \quad (\text{AISC F7-1, F7-5})$$

Note that the code does not cover the Box section flexure strength if the web is slender. The program uses the same flexure strength formula for Box sections with noncompact and slender webs, even though the formula applies only to noncompact section.

3.5.3.5 Pipe Sections

This section applies to pipe sections with D/t ratio less than $\frac{0.45E}{F_y}$. If a Pipe section violates this limit, the program reports an error.

The nominal flexural strength is the lowest value obtained according to the limit states of yielding (plastic moment) and local buckling. The same set of formulas is used for both major and minor axes of bending.

3.5.3.5.1 Yielding

$$M_n = M_p = F_y Z \quad (\text{AISC F8-1})$$

3.5.3.5.2 Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact sections,} \\ \left(\frac{0.021E}{\frac{D}{t}} + F_y \right) S, & \text{for noncompact sections, and} \\ F_{cr} S, & \text{for slender sections,} \end{cases} \quad (\text{AISC F8-1, F8-2, F8-3})$$

where, S is the elastic section modulus and F_{cr} is the critical buckling stress, where,

$$F_{cr} = \frac{0.33E}{\frac{D}{t}}. \quad (\text{AISC F8-4})$$

3.5.3.6 T-Shapes and Double Angle Sections

3.5.3.6.1 Major Axes Bending

The nominal flexural strength for T-Shapes and Double Angles bent about their major (3-3) axis, i.e., the axis perpendicular to the axis of symmetry, is taken as the lowest value obtained according to the limit states of yielding (plastic moment), lateral-torsional buckling, and flange local buckling.

3.5.3.6.1.1 Yielding

$$M_n = \begin{cases} M_p = F_y Z_{33} \leq M_y, & \text{for stems in compression, and} \\ M_p = F_y Z_{33} \leq 1.6M_y, & \text{for stems in tension.} \end{cases}$$

(AISC F9-1, F9-2, F9-3)

3.5.3.6.1.2 Lateral-Torsional Buckling

$$M_n = M_{cr} = \frac{\pi \sqrt{EI_y GJ}}{L_b} \left[B + \sqrt{1 + B^2} \right], \quad (\text{AISC F9-4})$$

where, B is taken conservatively as:

$$B = \pm 2.3 \left(\frac{d}{L_b} \right) \sqrt{\frac{I_y}{J}}. \quad (\text{AISC5 F9-5})$$

The plus sign for B applies when the stem is in tension ($M > 0$) and the minus sign applies when the stem is in compression ($M < 0$).

3.5.3.6.1.3 Flange Local Buckling

When the flange is under compression (i.e., when the factored moment M_r is positive), the nominal moment capacity is taken as follows:

$$M_n = F_{cr} S_{xc}, \quad (\text{AISC F9-6})$$

where, S_{xc} is the elastic section modulus about the compression flange, and F_{cr} is determined as follows:

$$F_{cr} = \begin{cases} F_y, & \text{for compact sections,} \\ F_y \left(1.19 - 0.50(b/t) \sqrt{\frac{F_y}{E}} \right), & \text{for noncompact sections, and} \\ \frac{0.69E}{(b/t)^2}, & \text{for slender sections,} \end{cases}$$

(AISC F9-1, F9-7, F9-8)

where,

$$\frac{b}{t} = \frac{b_f}{2t_f}, \quad (\text{for T-Shapes})$$

$$\frac{b}{t} = \frac{b_f}{t_f}, \quad (\text{for Double Angles})$$

and b_f and t_f are described in Figure 3-1.

When the flange is in tension, i.e., when the factored moment M_r is negative, this limit state is not considered in the program.

3.5.3.6.2 Minor Axes Bending

The nominal flexural strength for T-Shapes and Double Angles bent about their minor (2-2) axes, i.e., the axis of symmetry, is taken as the lowest value obtained according to the limit states of yielding (plastic moment) and flange local buckling.

3.5.3.6.2.1 Yielding

$$M_n = M_p = F_y Z_{22} \leq 1.6 F_y S_{22} \quad (\text{AISC F6-1})$$

where, S_{22} and Z_{22} are the section and plastic moduli about the minor axis, respectively.

3.5.3.6.2.2 Flange Local Buckling

$$M_n = \begin{cases} M_p, & \text{for compact flange,} \\ M_p - (M_p - 0.7F_y S_{22}) \left(\frac{\lambda - \lambda_{pf}}{\lambda_{rf} - \lambda_{pf}} \right), & \text{for noncompact flanges, and} \\ F_{cr} S_{22}, & \text{for slender flanges,} \end{cases} \quad (\text{AISC F6-6})$$

where,

$$F_{cr} = \frac{0.69E}{\lambda^2} \quad (\text{AISC 6-4})$$

$$\lambda = \frac{b_f}{2t_f} \quad (\text{for T-Shapes})$$

$$\lambda = \frac{b_f}{t_f} \quad (\text{for Double Angles})$$

and λ_{pf} and λ_{nf} are the limiting slendernesses for compact and noncompact flanges, respectively, as described in Table 3-5 (AISC B4.1).

3.5.3.7 Single Angle Sections

The nominal flexural strength of angle sections is conservatively calculated based on the principal axes of bending. The nominal flexural strength about the major principal axis is the lowest value obtained according to the limit states of yielding (plastic moment), lateral-torsional buckling, and leg local buckling.

3.5.3.7.1 Yielding

$$M_n = 1.5M_y, \quad (\text{AISC F10-1})$$

where, M_y is the yield moment about the axis of bending.

3.5.3.7.2 Lateral-Torsional Buckling

The nominal flexure strength for bending about the major principal axis for the limit state of lateral-torsional buckling is given as follows:

$$M_n = \begin{cases} \left(0.92 - \frac{0.17M_e}{M_y}\right) M_e, & \text{if } M_e \leq M_y, \text{ and} \\ \left(0.92 - 1.17\sqrt{\frac{M_y}{M_e}}\right) M_y \leq 1.5M_y, & \text{if } M_e > M_y, \end{cases}$$

(AISC F10-2, F-10-3)

where M_e is the elastic lateral-torsional buckling moment defined as follows:

$$M_e = \begin{cases} \frac{0.46Eb^2t^2C_b}{L} & \text{for equal-leg angles,} \\ \frac{4.9EI_zC_b}{L^2} \left(\sqrt{\beta_w^2 + 0.052\left(\frac{Lt}{r_z}\right)^2} + \beta_w \right) & \text{for unequal-leg angles.} \end{cases}$$

(AISC F10-5,6)

where,

C_b = lateral-torsional buckling modification factor for nonuniform moment diagram. It is computed using equation AISC F1-1. A limit on C_b is imposed ($C_b \leq 1.5$) in the program (AISC F10).

L = laterally unbraced length of the member. It is taken as the $\max(L_{22}, L_{33})$ in the program because L_{22} and L_{33} are not defined in the principal direction, in. (mm).

I_2 = minor principal axis moment of inertia, in.⁴ (mm⁴),

r_t = radius of gyration for the minor principal axis, in. (mm),

t = angle leg thickness, in. (mm). It is taken as $\min(t_b, t_f)$

β_w = a section property for unequal-legged angles. It is given as follows:

$$\beta_w = \frac{1}{I_w} \int_A z(w^2 + z^2) dA - 2z_0 \quad (\text{AISC Table C-F10.1})$$

β_w is positive for short leg in compression, negative for long leg in compression, and zero for equal-leg angles. If the long leg is in compression anywhere along the unbraced length of the member, the negative value of β_w should be used (AISC F10.2). It is conservatively taken as negative for unequal-leg angles.

z = coordinate along the minor principal axis

w = coordinate along the major principal axis

z_0 = coordinate of the shear center along the z -axis with respect to the centroid

I_w = major principal axis moment of inertia

I_z = minor principal axis moment of inertia.

In the preceding equation, M_y is taken as the yield moment about the major principal axis of bending, considering the possibility of yielding at the heel and both of the leg tips.

The nominal flexural strength for bending about the minor principal axis for the limit state of lateral-torsional buckling is not needed because the limit state of lateral-torsional buckling does not apply for minor axis bending.

3.5.3.7.3 Leg Local Buckling

The nominal flexural strength for bending about the major and minor principal axes of single angle sections for the limit state of h_g local buckling are given as follows:

$$M_n \begin{cases} 1.5F_y S_c & \text{if compact,} \\ F_y S_c \left(2.43 - 1.72 \left(\frac{b}{t} \right) \right) \sqrt{\frac{F_y}{E}} & \text{if noncompact, and} \\ \frac{0.71E}{(b/t)^2} S_c & \text{if slender,} \end{cases}$$

(AISC F10-7, F10-8, F10-9)

where,

S_c = elastic section modulus to the toe in compression relative to the axis of bending

t = thickness of the leg under consideration

b = outside width of the leg under consideration.

In calculating the bending strengths for single-angles for the limit state of leg local buckling, the capacities are calculated for both the principal axes considering the assumption that either of the two tips (toes) can be under compression. The minimum capacities are considered.

3.5.3.8 Rectangular Sections

This section applies to rectangular sections bent about either axis.

The nominal flexural strength is the lowest value obtained according to the limit states of yielding (plastic moment) and lateral-torsional buckling.

3.5.3.8.1 Yielding

$$M_n = M_p = F_y Z \leq 1.6M_y \quad (\text{AISC F11-1})$$

3.5.3.8.2 Lateral-Torsional Buckling

Limit state of lateral-torsional buckling does not apply to rectangular sections bent about their moving axis. For rectangular sections, M_n about major axis, is given by the following:

$$M_e = \begin{cases} M_p, & \text{if } \frac{L_b d}{t^2} \leq \frac{0.08E}{F_y}, \\ C_b \left[1.52 - 0.274 \left(\frac{L_b d}{t^2} \right) \frac{F_y}{E} \right] M_y \leq M_p, & \text{if } \frac{0.08E}{F_y} < \frac{L_b d}{t^2} \leq \frac{1.9E}{F_y}, \\ F_{cr} S_{33} \leq M_p, & \text{if } \frac{L_b d}{t^2} > \frac{1.9E}{F_y}, \end{cases}$$

(AISC F11-1, F11-2, F11-3)

where, F_{cr} is the critical buckling stress, which is given by

$$F_{cr} = \frac{1.9EC_b}{\frac{L_b d}{t^2}}, \quad (\text{AISC F11-4})$$

where, t is the width of the rectangular bar parallel to axis of bending; d is the depth of the rectangular bar; and L_b is the length unbraced against lateral displacement of the compression region or twist of the cross-section.

3.5.3.9 Circular Sections

The nominal flexural strength is the value obtained according to the limit states of yielding (plastic moment).

$$M_n = M_p = F_y Z \leq 1.6M_y \quad (\text{AISC F11-1})$$

For this section, the limit state of lateral-torsional buckling need not be considered (AISC F11.2(c)).

3.5.3.10 General Sections and Section Designer Sections

For General sections and Section Designer sections, the nominal major and minor direction bending strengths are assumed as:

$$M_n = M_y = SF_y.$$

The program does not check any lateral-torsional buckling, flange local buckling, web local buckling, or tension flange yielding. The program assumptions may not be conservative. The user is expected to calculate the capacity and overwrite it.

3.5.4 Nominal Shear Strength

The nominal shear strengths are calculated for shears along the geometric axes for all sections. For I-Shape, Box, Channel, Double Channel, T-Shape, Double Angle, Pipe, Circular and Rectangular sections, the principal axes coincide with their geometric axes. For Angle sections, principal axes do not coincide with their geometric axes.

In calculating nominal strength for shear, V_n , it is assumed that there is no intermedial stiffeners used to enhance shear strength of a section (AISC G2-2). The code allows the use of one of following methods: (a) the limit state of shear yielding and shear buckling without using tension-field-action (AISC G2); and (b) post buckling strength of the member or tension-field-action (AISC G3). The program uses the first method to calculate shear strengths.

The design shear strength, $\phi_v V_n$, and the allowable shear strength, V_n/Ω_v , are determined using the following factors.

For all sections in both the major and minor directions, except for the web of rolled I-Shaped members with $h/t_w \leq 2.24\sqrt{E/F_y}$

$$\phi_v = 0.9 \text{ (LRFD)} \quad \text{(AISC G1)}$$

$$\Omega_v = 1.67 \text{ (LRFD)} \quad \text{(AISC G1)}$$

For the web of rolled I-Shaped members with $h/t_w \leq 2.24\sqrt{E/F_y}$ and for major direction shear only

$$\phi_v = 1.0 \text{ (LRFD)} \quad \text{(AISC G2.1a)}$$

$$\Omega_v = 1.50 \text{ (ASD)} \quad \text{(AISC G2.1a)}$$

3.5.4.1 Shear in the Major Direction

The nominal shear strength for major direction, V_n , is evaluated according to the limit states of shear yielding and shear buckling

$$V_n = 0.6F_y A_w C_v, \quad (\text{AISC G2-1})$$

where A_w is the area of the web (overall depth times the web thickness, dt_w), and C_v is the web shear coefficient. The expressions of A_w and C_v differ from section to section, as follows.

3.5.4.1.1 I-Shapes

For all I-shaped members, A_w is taken as the overall depth of the member times the web thickness

$$A_w = dt_w. \quad (\text{AISC G2.1(b)})$$

For the webs of rolled I-shaped members with $h/t_w \leq 2.24\sqrt{E/F_y}$, C_v is taken as 1.

$$C_v = 1. \quad (\text{AISC G2-2})$$

For webs of all other I-shaped members, including both singly and doubly symmetric and both rolled and welded sections, C_v is taken as follows:

$$C_v = \begin{cases} 1.0, & \text{if } \frac{h}{t_w} \leq 1.10\sqrt{k_v E/F_y}, \\ \frac{1.10\sqrt{k_v E/F_y}}{h/t_w}, & \text{if } 1.10\sqrt{k_v E/F_y} < \frac{h}{t_w} \leq 1.37\sqrt{k_v E/F_y}, \text{ and} \\ \frac{1.51Ek_v}{(h/t_w)^2 F_y}, & \text{if } \frac{h}{t_w} > 1.37\sqrt{k_v E/F_y}, \end{cases} \quad (\text{AISC G2-3, G2-4, G2-5})$$

where k_v is the web plate buckling coefficient and it is taken as

$$k_v = 5. \quad (\text{AISC G2.1(b)(i)})$$

In the preceding expression, for rolled shapes, h is taken as the clear distance between flanges less the fillet or corner radii, and for built-up welded sections, h , is taken as the clear distance between flanges (AISC G2.1(b), B4.2).

It should be observed that the ϕ_v factor, also the Ω_v factor, differs for the web of rolled I-shaped members with $h/t_w \leq 2.24\sqrt{E/F_y}$ from the web of other I-shaped members.

3.5.4.1.2 Channel, Double Channel, and T-Shape Sections

A_w is taken as the overall depth of the member times the web thickness

$$A_w = dt_w \quad \text{for Channel sections,} \quad (\text{AISC G2.1(b)})$$

$$A_w = 2dt_w \quad \text{for Double Channel sections,} \quad (\text{AISC G2.1(b)})$$

$$A_w = dt_w \quad \text{for T-Shape sections.} \quad (\text{AISC G2.1(b)})$$

C_v is taken as follows:

$$C_v = \begin{cases} 1.0, & \text{if } \frac{h}{t_w} \leq 1.10\sqrt{k_v E/F_y}, \\ \frac{1.10\sqrt{k_v E/F_y}}{h/t_w} & \text{if } 1.10\sqrt{k_v E/F_y} < \frac{h}{t_w} \leq 1.37\sqrt{k_v E/F_y}, \text{ and} \\ \frac{1.51Ek_v}{(h/t_w)^2 F_y} & \text{if } \frac{h}{t_w} > 1.37\sqrt{k_v E/F_y}, \end{cases} \quad (\text{AISC G2-3, G2-4, G2-5})$$

where,

$$k_v = 5 \quad \text{for Channel and Double Channel sections} \quad (\text{AISC G2.1(b)(i)})$$

$$k_v = 1.2 \quad \text{for T-Shape sections} \quad (\text{AISC G2.1(b)(i)})$$

and for Channel and Double Channel sections, h is taken as the clear distance between flanges less the fillet or corner radii (AISC G2.1(b), B4.2); and for T-Shape sections, h is taken as the overall depth (AISC G2.1(b)).

3.5.4.1.3 Box Sections

A_w is taken as follows:

$$A_w = 2ht_w. \quad (\text{AISC G5})$$

C_v is taken as follows:

$$C_v = \begin{cases} 1.0, & \text{if } \frac{h}{t_w} \leq 1.10\sqrt{k_v E/F_y}, \\ \frac{1.10\sqrt{k_v E/F_y}}{h/t_w}, & \text{if } 1.10\sqrt{k_v E/F_y} < \frac{h}{t_w} \leq 1.37\sqrt{k_v E/F_y}, \text{ and} \\ \frac{1.51Ek_v}{(h/t_w)^2 F_y}, & \text{if } \frac{h}{t_w} > 1.37\sqrt{k_v E/F_y}, \end{cases}$$

(AISC G5, G2-3, G2-4, G2-5)

where,

$$k_v = 5 \quad \text{(AISC G5)}$$

$$h = d - 3t_f. \quad \text{(AISC G5)}$$

Note that the design thickness of the Box section can differ by a reduction factor from its nominal thickness if the welding process is ERW (AISC B3.12). The choice of reduction and the reduction factor C can be overwritten on a member-by-member basis.

3.5.4.1.4 Angle Sections

A_w and C_v are taken as follows:

$$A_w = bt \quad \text{(AISC G4)}$$

$$C_v = 1.0 \quad \text{(AISC G4)}$$

where b is the width of the leg resisting the shear force.

3.5.4.1.5 Double Angle Sections

A_w and C_v are taken as follows:

$$A_w = 2bt \quad \text{(AISC G4)}$$

$$C_v = 1.0 \quad \text{(AISC G4)}$$

where b is the width of the leg resisting the shear force.

3.5.4.1.6 Rectangular, Circular (Round), General and SD Sections

For these sections, A_w is calculated as the effective shear area from the basic principle of elastic shear distribution, and C_v is taken as 1 for simplicity.

3.5.4.1.7 Pipe Section

The nominal shear strength, V_n , of round HSS (i.e, Pipe sections) according to the limit state of shear yielding and shear buckling is taken as

$$V_n = F_{cr} A_g / 2 \quad (\text{AISC G6-1})$$

where,

$$F_{cr} = \frac{0.78E}{(D/t)^{3/2}} \leq 0.6F_y. \quad (\text{AISC G6-2b})$$

The code allows F_{cr} to be taken as the maximum of two alternate values. The program conservatively uses one of the two expressions only. In the preceding equations,

A_g = gross area of section based on design wall thickness

D = outside diameter

t = design wall thickness.

The design wall thickness is equal to 0.93 times the nominal wall thickness for ERW HSS, and equal to the nominal wall thickness for SAW HSS. However, the choice of thickness reduction and the reduction factor can be overwritten in the program on a member-by-member basis.

3.5.4.2 Shear in Minor Direction

The nominal shear strength for minor directions, V_{n3} , is evaluated according to the limit states of shear yielding and shear buckling as follows:

$$V_n = 0.6F_y A_w C_v, \quad (\text{AISC G2-1})$$

where, A_w is the shear area for minor direction shear, and C_v is the web shear coefficient. The expression of A_w and C_v differs from section to section as follows.

3.5.4.2.1 I-Shapes, Channel, Double Channel, and T- Shapes

A_w is taken as the sum of flange areas.

$$A_w = \begin{cases} 2b_f t_f & \text{Doubly Symmetric I-Shapes} \\ b_{fb} t_{fb} + b_{ft} t_{ft} & \text{Singly Symmetric I-Shapes} \\ 2b_f t_f & \text{Channels} \\ 4b_f t_f & \text{Double Channels} \\ b_f t_f & \text{T Shapes} \end{cases} \quad (\text{AISC G7})$$

C_v is taken as follows:

$$C_v = \begin{cases} 1.0, & \text{if } \frac{h}{t_w} \leq 1.10\sqrt{k_v E/F_y}, \\ \frac{1.10\sqrt{k_v E/F_y}}{h/t_w}, & \text{if } 1.10\sqrt{k_v E/F_y} < \frac{h}{t_w} \leq 1.37\sqrt{k_v E/F_y}, \text{ and} \\ \frac{1.51Ek_v}{(h/t_w)^2 F_y}, & \text{if } \frac{h}{t_w} > 1.37\sqrt{k_v E/F_y}, \end{cases} \quad (\text{AISC G7, G2-3, G2-4, G2-5})$$

where h/t_w is really meant for flange and is taken as follows,

$$\frac{h}{t_w} = \begin{cases} b_f/2t_f & \text{I Shapes} \\ b_f/t_f & \text{Channels} \\ b_f/t_f & \text{Double Channels} \\ b_f/2t_f & \text{T Shapes} \end{cases} \quad (\text{AISC G7})$$

and k_v is taken as 1.2,

$$k_v = 1.2. \quad (\text{AISC G7})$$

All dimensions used in the preceding equation are explained in Figure 3-1. For Singly Symmetric I-Shapes where each flange has its own properties, the shear capacity contribution is calculated for each flange separately based on its own dimensions, and then the combinations are added together.

3.5.4.2.2 Box Sections, Angles, and Double Angles

The shear capacity in the minor direction, V_{n3} , is calculated in exactly the same way as for calculation of the major shear capacity, V_{n2} , except that the appropriate dimensions are used (AISC G4, G5, G1).

3.5.4.2.3 Pipe Sections

The shear capacity in the minor direction, V_{n3} , is exactly the same as that for major direction (AISC G6).

3.5.4.2.4 Rectangular, Circular (Round), General and SD Sections

For these sections, A_w is calculated as the effective shear area from the basic principle of elastic stress distribution. C_v is taken as 1 for simplicity. Then, equation G2-1 is used to calculate the shear capacity.

3.5.5 Nominal Torsional Strength

The nominal torsion strengths are calculated for closed sections such as Boxes and Pipes only. Torsion is ignored in design for all other section types.

The design torsional strength, $\phi_T T_n$, and the allowable torsional strength, T_n/Ω_T , are determined using the following resistance and safety factors:

$$\phi_T = 0.90 \text{ (LRFD)} \quad \text{(AISC H3.1)}$$

$$\Omega_T = 1.67 \text{ (ASD)} \quad \text{(AISC H3.1)}$$

The nominal torsional strength, T_n , according to the limit states of torsional yielding and torsional buckling, is as follows:

$$T_n = F_{cr} C, \quad \text{(AISC H3-1)}$$

where C is the torsional shear constant, and F_{cr} is the critical buckling stress.

For round HSS (i.e., Pipe sections), C is taken conservatively as

$$C = \frac{\pi(D-t)^2 t}{2} \quad \text{(AISC H3.1 Note)}$$

F_{cr} is taken as,

$$F_{cr} = \max(F_{cr1}, F_{cr2}) \leq 0.6F_y, \quad \text{(AISC H3.1)}$$

where,

$$F_{cr1} = \frac{1.23E}{\sqrt{\frac{L}{D} \left(\frac{D}{t}\right)^{5/4}}}, \text{ and} \quad (\text{AISC H3-2a})$$

$$F_{cr2} = \frac{0.60E}{\left(\frac{D}{t}\right)^{3/2}}. \quad (\text{AISC H3-2b})$$

In the preceding equations,

L = torsional unbraced length of the member, L_{LTB} . This length is taken as the minor direction unbraced length for flexural buckling, L_{22} , by default. However, this length can be overwritten in the program.

D = outside diameter of the Pipe section

t = design wall thickness

For regular HSS (i.e., Box sections),

$$C = 2(b_f - t_w)(d - t_f) \{ \min(t_w, t_f) \} - 4.5(4 - \pi) \{ (\min(t_f, t_w))^3 \} \quad (\text{AISC H3.1})$$

$$F_{cr} = \begin{cases} 0.6F_y, & \text{if } h/t \leq 2.45\sqrt{E/F_y}, \\ 0.6F_y \frac{2.45\sqrt{E/F_y}}{(h/t)}, & \text{if } 2.45\sqrt{E/F_y} < h/t \leq 3.07\sqrt{E/F_y}, \text{ and} \\ 0.458\pi^2 \frac{E}{(h/t)^2}, & \text{if } 3.07\sqrt{E/F_y} < h/t \leq 26.0. \end{cases}$$

(AISC H3-3, H3-4, H3-5)

The variables b_f , t_w , d , t_f , h and t used in the preceding expression have been explained in Figure 3-1. In calculating h/t , the maximum of the ratio of depth to thickness and width to thickness are considered.

Here t is the design thickness. The design wall thickness is equal to 0.93 times the nominal wall thickness for ERW HSS and equal to the nominal wall thick-

ness for SAW HSS. However, the choice of thickness reduction and the reduction factor can be overwritten in the program on a member-by-member basis.

3.6 Design of Members for Combined Forces

Previous sections of this design manual address members subject to only one type of force, namely axial tension, axial compression, flexure or shear. This section addresses the design of members subject to a combination of two or more of the individual forces.

In the calculation of the demand/capacity (D/C) ratios, first, for each station along the length of the member, the actual member force/moment components are calculated for each design combination. Then, the corresponding capacities are calculated. Then, the D/C ratios are calculated at each station for each member under the influence of each of the design combinations. The controlling D/C ratio is then obtained, along with the associated station and design combination. A D/C ratio greater than the D/C ratio limit (whose default value is 1.0) indicates exceeding a limit state.

During the design, the effect of the presence of bolts or welds is not considered.

3.6.1 Doubly and Singly Symmetric Members Subjected to Flexure and Axial Compression

The interaction of flexure and axial compression in all members with Doubly Symmetric sections (I-Shapes, Double Channel, Box, Pipe, Solid Circular, Solid Rectangular) and Singly Symmetric sections (Channel, T-Shape, Double Angle), with some exceptional cases, is given as follows:

$$\text{For } \frac{P_r}{P_c} \geq 0.2$$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\frac{M_{r33}}{M_{c33}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0. \quad (\text{AISC H1-1a})$$

$$\text{For } \frac{P_r}{P_c} < 0.2$$

$$\frac{P_r}{2P_c} + \left(\frac{M_{r33}}{M_{c33}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0, \quad (\text{AISC H1-1b})$$

where, P_r and P_c are the required and available axial strengths; M_r and M_c are the required and available flexural strengths; and 3 and 2 represent the strong and weak axes, respectively.

Depending on the selected design provisions (LRFD or ASD), the aforementioned terms are defined as follows:

For design according to LRFD provisions:

P_t = required axial compressive strength using LRFD load combinations

P_c = design axial compressive strength = $\phi_c P_n$

M_r = required flexural strength using LRFD load combinations

M_c = design flexural strength = $\phi_b M_n$

ϕ_c = resistance factor for compression = 0.90

ϕ_b = resistance factor for flexure = 0.90

For design according to ASD provisions:

P_t = required axial compressive strength using ASD load combinations

P_c = allowable axial compressive strength = P_n/Ω_c

M_r = required flexural strength using ASD load combinations

M_c = allowable flexural strength = M_n/Ω_b

Ω_c = safety factor for compression = 1.67

Ω_b = safety factor for flexure = 1.67

As an exception, for Circular and Pipe sections, an SRSS (Square Root of Sum of Squares) combination is made first of the two bending components before adding the axial load component, instead of the single algebraic addition as implied by the interaction equations given by AISC H1-1a and AISC H1-1b. The resulting interaction equation is given by the following:

$$\text{For } \frac{P_r}{P_c} \geq 0.2$$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\sqrt{\left(\frac{M_{r33}}{M_{c33}} \right)^2 + \left(\frac{M_{r22}}{M_{c22}} \right)^2} \right) \leq 1.0.$$

$$\text{For } \frac{P_r}{P_c} < 0.2$$

$$\frac{P_r}{2P_c} + \left(\sqrt{\left(\frac{M_{r33}}{M_{c33}} \right)^2 + \left(\frac{M_{r22}}{M_{c22}} \right)^2} \right) \leq 1.0.$$

The philosophy behind the preceding modification is that the engineer has the freedom to choose the principal axis. The engineer can easily choose the principal axis to match with the resultant moment so that the design is always based on the uniaxial bending with axial force. In that case, the moment will be the resultant (SRSS) moment from the two components. The resultant D/C ratio calculated using the preceding equations will match the calculated D/C ratio from the pure resultant moment for the Pipe section. The reason is that M_n for the Pipe section is independent of the K and L factors. However, for solid circular (round) sections, the resultant stress ratio calculated using the preceding equations will not match exactly with the calculated D/C ratio from the pure resultant moment because M_n for this section depends on the K and L factors, which are known for only two given principal directions.

As an exception, for members with double symmetric sections in flexure and compression with negligible minor axis bending moment, two independent limit states, namely in-plane instability and out-of-plane buckling, also are considered separately considering the combined approach provided in AISC equations H1-1a and H1-1b. The minimum ratio provided by the original approach (AISC H1-1a, H1-1b) and the alternative approach described herein are taken as the resulting D/C ratio.

- a) For the limit state of in-plane instability, equations H1-1a and H1-1b are used with M_c having a different meaning.

$$\text{For } \frac{P_r}{P_c} \geq 0.2$$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\frac{M_{r33}}{M_{c33, \text{NoLTB}}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0. \quad (\text{AISC H1-1a, H1.3a})$$

For $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{r33}}{M_{c33, \text{NoLTB}}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0, \quad (\text{AISC H1-1b, H1.3a})$$

where, all the terms in the preceding equations are the same as explained earlier in this section, except $M_{c33, \text{NoLTB}}$ is explained as follows:

For LRFD:

$M_{c33, \text{NoLTB}} = \phi_b M_{n33}$ = design flexural strength determined in accordance with Chapter F, except that in determining M_{n33} , in this case, the lateral torsional buckling is not considered.

For ASD:

$M_{n33, \text{NoLTB}} = M_{n33} / \Omega_b$ = allowable flexural strength determined in accordance with Chapter F, except that in determining M_{n33} , in this case, the lateral torsional buckling is not considered.

In general, $M_{n33, \text{NoLTB}}$ is either larger than the regular M_{n33} or equal to (for Pipe sections) the regular M_{n33} . The negligibility of the minor axis moment is tested in the program by using a tolerance (0.001) multiplied by the minor direction capacity (M_{n22}).

- b) For the limit state of out-of-plane buckling, the following interaction equation is used

$$\frac{P_r}{P_{co}} + \left(\frac{M_{r33}}{M_{c33}} \right)^2 \leq 1.0 \quad (\text{AISC H1-2})$$

where

P_{co} = available compressive strength considering out-of-plane bending; it is taken equal to $\phi_c P_n$,

M_{c33} = available flexural strength considering all limit states, including lateral-torsional buckling.

As an exception, any singly-symmetric I-Shape section with I_{yc}/I_y beyond the range of $0.1 \leq I_{yc}/I_y \leq 0.9$ is considered beyond the scope of the code (AISC H.1, F13.2). Those sections are not checked by the program.

As an exception, all General sections and section created using Section Designer are treated as Doubly or Singly Symmetric sections. The equations H1-1a and H1-1b are use for calculation of the D/C ratios.

The program considers the left-hand side to calculate the D/C ratio. The D/C ratio is really compared with the D/C ratio limit rather than 1. By default, the D/C ratio limit is 0.95. This limit can be changed in the Preferences.

3.6.2 Doubly and Singly Symmetric Members Subjected to Flexure and Axial Tension

The interaction of flexure and axial tension in all members with Doubly Symmetric sections (I, Double Channel, Box, Pipe, Solid Circular, Solid Rectangular) and Singly Symmetric sections (Channel, T-Shapes, Double Angle), with some exceptional cases, are given as follows:

For $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\frac{M_{r33}}{M_{c33}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0 \quad (\text{AISC H1-2, H1-1a})$$

For $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{r33}}{M_{c33}} + \frac{M_{r22}}{M_{c22}} \right) \leq 1.0, \quad (\text{AISC H1-2, H1-1b})$$

where, P_r and P_c are the required and available axial strengths; M_r and M_c are the required and available flexural strengths; and 3 and 2 represent the strong and weak axes, respectively.

Depending on the selected design provisions (LRFD or ASD), the aforementioned terms are defined as follows:

For design in accordance with LRFD provisions:

P_t = required axial tensile strength using LRFD load combinations

P_c = design axial tensile strength = $\phi_c P_n$

M_r = required flexural strength using LRFD load combinations

M_c = design flexural strength = $\phi_b M_n$

ϕ_t = resistance factor for tension (0.90 yielding, 0.75 rupture) (AISC D2)

ϕ_b = resistance factor for flexure = 0.90

For design in accordance with ASD provisions:

P_t = required axial compressive strength using ASD load combinations

P_c = allowable axial compressive strength = P_n/Ω_c

M_r = required flexural strength using ASD load combinations

M_c = allowable flexural strength = M_n/Ω_b

Ω_t = safety factor for tension (1.67 yielding, 2.00 rupture) (AISC D2)

Ω_b = safety factor for flexure = 1.67

As an exception, for Circular and Pipe sections, an SRSS (Square Root of Sum of Squares) combination is made first of the two bending components before adding the axial load component, instead of the single algebraic addition as implied by the interaction equations given by AISC H1-1a and AISC H1-1b. The resulting interaction equation is given by the following:

For $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9} \left(\sqrt{\left(\frac{M_{r33}}{M_{c33}} \right)^2 + \left(\frac{M_{r22}}{M_{c22}} \right)^2} \right) \leq 1.0$$

For $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\sqrt{\left(\frac{M_{r33}}{M_{c33}}\right)^2 + \left(\frac{M_{r22}}{M_{c22}}\right)^2} \right) \leq 1.0.$$

As an exception, any single-symmetric I-Shape section with I_{yc}/I_y beyond the range of $0.1 \leq I_{yc}/I_y \leq 0.9$ is considered beyond the scope of the code (AISC H.1, F13.2). These sections are not checked by the program.

As an exception, all General sections and section created using Section Designer are treated as Doubly or Singly Symmetric sections. The equations H1-1a and H1-1b are use for calculation of the D/C ratios.

The program considers the left-hand side to calculate the D/C ratio. The D/C ratio is really compared with the D/C ratio limit rather than 1. By default, the D/C ratio limit is 0.95. This limit can be changed in the Preferences.

3.6.3 Unsymmetric Members Subjected to Flexure and Axial Force

Unlike I-Shapes, Box, Channel, Double Channel, T-Shapes, Double Angle, Pipe, Circular, and Rectangular sections, the principal axes of unsymmetric (unequal leg) Single Angle sections do not coincide with their geometric axes. For Single Angle sections, the principal properties of the section are determined. The forces are resolved in the principal directions (w and z). The iteration of flexure and axial stress is calculated as follows:

$$\left| \frac{f_a}{F_a} + \frac{f_{bw}}{F_{bw}} + \frac{f_{bz}}{F_{bz}} \right| \leq 1.0 \quad (\text{AISC H2-1})$$

where f_a and F_a are the required and available axial stresses at the point of consideration; f_b and F_b are required and available bending stresses; w is the subscript related to the major principal axis bending; and z is the subscript related to the minor principal axis bending.

For design in accordance with LRFD provisions:

- f_a = required axial stress using LRFD load combinations
- F_a = design axial stress = $\phi_c F_{cr}$ or $\phi_t F_y$
- f_{bw}, f_{tz} = required flexural stress using LRFD load combinations

$$F_{bw}, F_{tz} = \text{design flexural stress} = \frac{\phi_b M_n}{S}$$

$$\phi_c = \text{resistance factor for compression} = 0.90$$

$$\phi_f = \text{resistance factor for tension (0.9 for yielding, 0.75 for rupture)} \\ \text{(Section AISC D2)}$$

$$\phi_b = \text{resistance factor for flexure} = 0.90$$

For design in accordance with ASD provisions:

$$f_a = \text{required axial stress using ASD load combinations}$$

$$F_a = \text{allowable axial stress} = F_{cr} / \Omega_c \text{ or } F_y / \Omega_t$$

$$f_{bw}, f_{bz} = \text{required flexural stress using ASD load combinations}$$

$$F_{bw}, F_{bz} = \text{allowable flexural stress} = \frac{M_n}{\Omega_b S}$$

$$\Omega_c = \text{safety factor for compression} = 1.67$$

$$\Omega_f = \text{safety factor for tension (1.67 for yielding, 2.00 for rupture)} \\ \text{(Section AISC D2)}$$

$$\Omega_b = \text{safety factor for flexure} = 1.67$$

For General sections and Section Designer sections, it is assumed that the section properties are given in terms of principal directions. These two types of sections are treated as symmetric sections for interaction purposes.

3.6.4 Members Subject to Torsion, Flexure, Shear and Axial Force

The interaction of torsion, flexure, shear, and axial force is considered only for Box and Pipe sections and only if the torsion is significant. Torsion is considered significant when the required torsional strength, T_r , is more than 20% of the available torsional strength, T_c (AISC H3.2). The interaction of torsion with other forces is ignored when

$$T_r \leq 0.2T_c, \quad \text{(AISC H3.2)}$$

and for members with Box sections, the interaction of torsion, shear, flexure and axial force is given by

$$\frac{P_r}{P_c} + \left(\frac{M_{r33}}{M_{c33}} + \frac{M_{r22}}{M_{c22}} \right) + \left(\frac{V_{r3}}{V_{c3}} + \frac{V_{r2}}{V_{c2}} + \frac{T_r}{T_c} \right)^2 \leq 1.0, \quad (\text{AISC H3-6})$$

and for members with Pipe sections, the interaction of torsion, shear, flexure, and axial forces is given by

$$\frac{P_r}{P_c} + \left(\sqrt{\left(\frac{M_{r33}}{M_{c33}} \right)^2 + \left(\frac{M_{r22}}{M_{c22}} \right)^2} \right) + \left(\frac{V_{r3}}{V_{c3}} + \frac{V_{r2}}{V_{c2}} + \frac{T_r}{T_c} \right)^2 \leq 1.0, \quad (\text{AISC H3-6})$$

where, P_r and P_c are the required and available axial strength; M_r and M_c are required and available flexural strength; V_r and V_c are required and available shear strength; and T_r and T_c are required and available torsional strength, respectively.

For design in accordance with LRFD provisions:

P_r = required axial strength using LRFD load combinations

P_c = design compressive/tensile strength = $\phi_c P_n$ or $\phi_t P_n$

M_r = required flexural strength using LRFD load combinations

M_c = design flexural strength = $\phi_b M_n$

V_r = required shear strength using LRFD load combinations

V_c = design shear strength = $\phi_v V_n$

T_r = required torsional strength using LRFD load combinations

T_c = design torsional strength = $\phi_T T_n$

ϕ_c = resistance factor for compression = 0.90

ϕ_t = resistance factor for tension (0.9 for yielding, 0.75 for rupture) (from AISC D2)

ϕ_b = resistance factor for flexure = 0.90

ϕ_v = resistance factor for shear = 0.90

ϕ_T = resistance factor for torsion = 0.9

For design in accordance with ASD provisions:

P_r = required axial strength using ASD load combinations

P_c = allowable compressive/tensile strength = P_n / Ω_c or P_n / Ω_t

M_r = required flexural strength using ASD load combinations

M_c = allowable flexural strength = M_n / Ω_b

V_r = required shear strength using ASD load combinations

V_c = allowable shear strength = V_n / Ω_v

T_r = required torsional strength using ASD load combinations

T_c = allowable torsional strength = T_n / Ω_r

Ω_c = safety factor for compression = 0.90

Ω_t = safety factor for tension (1.67 for yielding, 2.0 for rupture) (from AISC D2)

Ω_b = safety factor for flexure = 0.90

Ω_v = safety factor for shear = 0.90

Ω_r = safety factor for torsion = 0.90

Chapter 4

Special Seismic Provisions (ANSI/AISC 341-05)

This chapter provides a detailed description of the algorithms related to special seismic provisions in the design/check of structures in accordance with the "ANSI/AISC 341-05—Seismic Provisions for Structural Steel Buildings Including Supplement No. 1" (AISC 2005). The code option "AISC 360-05/IBC 2006" covers these provisions. The same code option covers "ANS/AISC 360-05—Specifications for Structural Steel Building" (AISC 2005a, b) as the basic code. The implementation covers load combinations from "ASCE/SEI 7-05," which is described in the section "Design Loading Combination" of Chapter 3. The loading based on "ASCE/SEI 7-05" has been described in a separate document entitled "CSI Lateral Load Manual" (CSI 2007). References are also made to IBC 2006 in this chapter.

For referring to pertinent sections of the corresponding code, a unique prefix is assigned for each code.

- Reference to the ANSI/AISC 360-05 code carries the **AISC** prefix.
- Reference to the ANSI/AISC 341-05, Part I code carries the **AISC SEISMIC** prefix or sometimes **SEISMIC** only.
- Reference to the ASCE/SEI 7-05 code carries the **ASCE** prefix.
- Reference to the IBC 2006 code carries the **IBC** prefix.

4.1 Notations

Most of the notations used in this chapter have been described previously in Chapter 3. Any additional notations used in this chapter are described herein.

| | |
|------------|---|
| S_{DS} | Design earthquake spectral response acceleration parameter at short period (ASCE 11.4.4) |
| P | Redundancy factor (ASCE 12.3.4) |
| Ω_O | Overstrength factor (ASCE Table 12.2-1) |
| E_n | Effect of horizontal component of design seismic force, including the effect of P (ASCE 12.4.2.1) |
| E_v | Effect of vertical component of design seismic force (ASCE 12.4.2.2) |
| E_{nm} | Horizontal seismic load effects with overstrength factor (ASCE 12.4.3.1) |
| Q_E | Effects of horizontal seismic forces (ASCE 12.4.2.1, 12.4.3.1, 12.8.1) |

4.2 Design Preferences

The steel frame design Preferences are basic assignments that apply to all of the steel frame members. The Preferences are described in Appendix B. Tables B-1, B-2, and B-3 list the steel frame design Preferences. The following steel frame design Preferences are relevant to the special seismic provisions.

- Framing Type
- Notional Load Coefficient
- Seismic Design Category
- Ignore Seismic Code?
- Ignore Special Seismic Load?
- Is Doubler Plate Plug Welded?

4.3 Overwrites

The steel frame design Overwrites are basic assignments that apply only to those elements to which they are assigned. The overwrites are described in Appendix C. Table C-1 lists the steel frame design Overwrites. The following steel frame design overwrites are relevant to the special seismic provisions.

- Frame Type
- Omega0
- Overstrength factor, R_y

4.4 Supported Framing Types

The code (ANSI/AISC 341-05) now recognizes the following types of framing systems (AISC SEISMIC 9, 10, 11, 12, 13, 14, 15, 16, 17).

| Framing Type | References |
|---|-----------------|
| SMF (Special Moment Frame) | AISC SEISMIC 9 |
| IMF (Intermediate Moment Frame) | AISC SEISMIC 10 |
| OMF (Ordinary Moment Frame) | AISC SEISMIC 11 |
| STMF (Special Truss Moment Frame) | AISC SEISMIC 12 |
| SCBF (Special Concentrically Moment Frame) | AISC SEISMIC 13 |
| OCBF (Ordinary Concentrically Moment Frame) | AISC SEISMIC 14 |
| EBF (Eccentrically Moment Frame) | AISC SEISMIC 15 |
| BRBF (Buckling Restrained Moment Frame) | AISC SEISMIC 16 |
| SPSW (Special Plate Shear Wall) | AISC SEISMIC 17 |

With regard to these framing types, the program has implemented specifications for all types of framing systems, except STMF, BRBF, and SPSW. Implementing those three types of framing requires further information about modeling.

The program recognizes the OCBF framing in its two separate incarnations: OCBF for regular Ordinary Concentrically Braced Frames (AISC SEISMIC 14) and OCBFI for (base) Isolated Ordinary Concentrically Braced Frames (AISC SEISMIC 14.5).

By default, the frame type is taken as Special Moment Frame (SMF) in the program. However, the default frame type can be changed in the Preference form for all frames or in the Overwrites form on a member-by-member basis (Chapter 3). If a frame type Preference is revised in an existing model, the revised frame type does not apply to frames that have already been assigned a frame type through the Overwrites; the revised Preference applies only to new frame members added to the model after the Preference change and to the old frame members that were not assigned a frame type through the Overwrites.

4.5 Applicability of the Seismic Requirements

Ideally, the special seismic provisions shall apply when the seismic response modification factor, R , is taken as greater than 3, regardless of the seismic design category (AISC SEISMIC 1). R is specified by the applicable building code (local code or IBC). IBC actually refers to ASCE 7-05 for the value of R (IBC 2205.2.1). Again, when R is taken as 3 or less, the structure is not required to satisfy these provisions, unless specifically required by the applicable building code.

The applicable building code generally restricts buildings designed with an R factor of 3 or less to Seismic Design Category (SDC) A, B, or C; however, some systems that have R factors less than 3 are permitted in SDC D, E, or F (IBC 2205.2, ASCE 12.2.1, ASCE Table 12.2-1).

The program assumes that the special seismic provisions are applicable to any structural steel structure that is assigned to SDC D, E, or F, irrespective of the value of R , and to any structural steel structure designed with an R greater than 3 and that is assigned to SDC A, B, or C. In addition, the program allows the user to change the default applicability of special seismic provisions using the "Ignore Seismic Code?" Preference item.

4.6 Design Load Combinations

The program creates the default design load combinations based on the specification of ASCE 7-05 code. The default load combinations are generated differently when the LRFD (ASCE 2.3.2) and ASD (ASCE 2.4.1) provisions are chosen. The default combinations have been described in "Design Loading Combinations" in Chapter 3. Additional information may be found in "Design Load Combinations" in Chapter 2. The user may change the default load combinations if the governing code is different (AISC SEISMIC 4.1).

The program assumes that the defined earthquake load is really the strength level earthquake, which is equivalent to θ_E as defined in Section 12.4.2.1 in ASCE 7-05 code. For a regular earthquake, load is considered to have two components: horizontal, E_h and vertical E_v , which are taken as

$$E_h = \rho\theta_E, \quad (\text{ASCE 12.4.2.1})$$

$$E_v = 0.2S_{DS}D, \quad (\text{ASCE 12.4.2.2})$$

where, ρ is the redundancy factor as defined in Section 12.3.4 of ASCE 7-05, and the S_{DS} is the design earthquake spectral response acceleration parameters at short periods, as defined in Section 11.4.4 of ASCE 7-05 code.

Effectively, the seismic load combinations for the LRFD provision become

$$(1.2 + 0.2S_{DS}) \text{ DL } \pm \rho\theta_E \quad (\text{ASCE 2.3.2-7, 12.4.2.3})$$

$$(1.2 + 0.2S_{DS}) \text{ DL } \pm \rho\Omega_E + 1.0 \text{ LL} \quad (\text{ASCE 2.3.2-7, 12.4.2.3})$$

$$(0.9 - 0.2S_{DS}) \text{ DL } \pm \rho\Omega_E. \quad (\text{ASCE 2.3.2-7, 12.4.2.3})$$

The seismic load combinations for the ASD provision become

$$(1.0 + 0.14S_{DS}) \text{ DL } \pm 0.7\rho\Omega_E \quad (\text{ASCE 2.4.1-5, 12.4.2.3})$$

$$(1.0 + 0.105S_{DS}) \text{ DL } \pm 0.75(0.7\rho)\Omega_E + 0.75 \text{ LL} \quad (\text{ASCE 2.4.1-6, 12.4.2.3})$$

$$(0.6 - 0.14S_{DS}) \text{ DL } \pm 0.7\rho\Omega_E. \quad (\text{ASCE 2.4.1-7, 12.4.2.3})$$

The program automatically considers seismic load effects, including overstrength factors (ASCE 7-05 12.4.3), as special load combinations that are created automatically from each load combination involving seismic loads. In that case, the horizontal component of the force is represented by E_{hm} , and vertical component of the force is represented by E_v , where,

$$E_{hm} = \Omega_o Q_E \text{ and} \quad (\text{ASCE 12.4.3.1})$$

$$E_v = 0.2S_{DS}D. \quad (\text{ASCE 12.4.2.2})$$

Effectively, the special seismic combinations for the LRFD provision are

$$(0.9 - 0.2S_{DS}) \text{ DL} \pm \Omega_o Q_E \quad (\text{ASCE 2.3.2-7, 12.4.3.2})$$

$$(1.2 + 0.2S_{DS}) \text{ DL} \pm \Omega_o Q_E + 1.0\text{LL} \quad (\text{ASCE 2.3.2-5, 12.4.3.2})$$

and for the ASD provision, the combinations are

$$(1.0 + 0.14S_{DS}) \text{ DL} \pm 0.7\Omega_o\theta_E \quad (\text{ASCE 2.4.1-7, 12.4.3.2})$$

$$(1.0 + 0.105S_{DS}) \text{ DL} \pm 0.75(0.7\Omega_o)\theta_E + 0.75\text{LL} \quad (\text{ASCE 2.4.1-6, 12.4.3.2})$$

$$(0.6 - 0.14S_{DS}) \text{ DL} \pm 0.7\Omega_o\theta_E \quad (\text{ASCE 2.4.1-7, 12.4.3.2})$$

The factor S_{DS} is described earlier in this section. Ω_o is the seismic force amplification factor that is required to account for structural overstrength. The factor Ω_o is the overstrength factor, and it should be picked up from ASCE 7-05, Table 12.2-1 by the user and input in the Preferences and auto-seismic load definition. The default value of Ω_o is taken as 3.0 in the program. If the user defines one or more auto-seismic loads, the values of Ω_o are taken as the maximum of all the Ω_o defined for each auto-seismic load case. Also if the user defines special seismic data that includes an Ω_o value and requests that the program include the special seismic design data, then this Ω_o takes precedence over the default values and those defined for the auto-seismic load cases. Moreover, Ω_o can be overwritten for each individual member. The overwritten Ω_o gets the highest precedence. The guideline for selecting a reasonable value for Ω_o can be found in ASCE 7-05, Table 12.2-1.

Those combinations involving Ω_0 are internal to the program. The user does NOT need to create additional load combinations for those load combinations. The special circumstances for which those load combinations are additionally checked are described later in this chapter, as appropriate. The special loading combination factors are applied directly to the load cases. It is assumed that any required scaling (such as may be required to scale response spectra results) has already been applied to the load cases.

The program assumes that the seismic loads defined as the strength level load is the program load case. Otherwise, the factors ρ , Ω_0 , and S_{DS} will be unable to scale the load to the desired level.

4.7 Classification of Sections for Local Buckling

The sections are classified in the program as Seismically Compact, Compact, Noncompact, Slender, and Too Slender. The sections are classified as Compact, Noncompact, or Slender sections in accordance with Section B4 of the regular code (AISC B4, AISC Table B4.1). The limiting width/thickness ratios, λ_p , λ_r , and λ_s , that demarcate the slenderness limits for Compact, Noncompact, Slender and Too Slender sections were given in Table 3-5 in "Classification of Sections for Local Buckling" in Chapter 3.

Seismically compact sections are capable of developing the full plastic strength before local buckling occurs when the section goes through low cycle fatigue and withstands reversal of load under seismic conditions. The width/thickness ratio (λ) should be less than the limit, λ_{ps} , for the section to be Seismically Compact. The limiting width/thickness ratio, λ_{ps} , for compression elements is given in Table 4-1 and is based on the Seismic code (AISC SEISMIC 8.2, Table I-8-1). The Seismically Compact sections are reported as "Seismically Compact," or sometimes as "Seismic" only for brevity in the design output.

Table 4-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

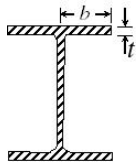
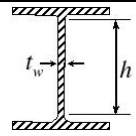
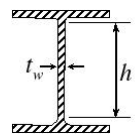
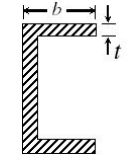
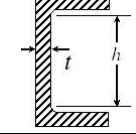
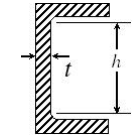
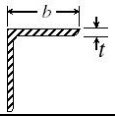
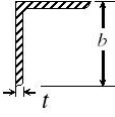
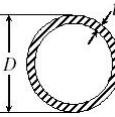
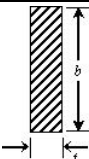
| Section Type | Description of Element | Graphical Example | Given Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Elements | Applicable Situation with Code Reference |
|-------------------------------------|---|---|----------------|------------------------------------|---|---|
| | | | | | Seismically Compact (λ_{ps}) | |
| Singly or Doubly Symmetric I Shapes | Flexural or uniform compression in flanges of rolled and welded I-Shaped sections |  | 1,2 | $b_f / 2t_f$ | $0.30 \sqrt{E/F_y}$ | Beams in SMF (SEISMIC 9) Beams in BRBF (SEISMIC 16) Links in EBF (SEISMIC 15) Columns in SMF (SEISMIC 9) Columns in SCBF (SEISMIC 13) Columns in BRBF (SEISMIC 16) Braces in SCBF (SEISMIC 13) Braced in OCBF (SEISMIC 14) |
| | Flexural compression in beam web |  | 9 | h/t_w | $2.45 \sqrt{E/F_y}$ | Beams in SMF (SEISMIC 9) |
| | Webs in flexural compression or combined flexural and axial compression |  | 10 | h/t_w | If $C_a \leq 0.125$ $3.14 \sqrt{\frac{E}{F_y}} (1 - 1.54C_a)$ If $C_a > 0.125$ $1.12 \sqrt{\frac{E}{F_y}} (2.33 - C_a) \geq 1.49 \sqrt{\frac{E}{F_y}}$ | Beams in BRBF (SEISMIC 16) Columns in SMF (SEISMIC 9) Columns in SCBF (SEISMIC 13) Columns in EBF (SEISMIC 15) Columns in BRBF (SEISMIC 16) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |
| Channel | Flexural or Uniform compression in flanges |  | 4 | b_f / t_f | $0.30 \sqrt{E/F_y}$ | Columns in SCBF (SEISMIC 13) Braces in SCBF (SEISMIC 13) |
| | Flexural compression in beam web |  | 9 | h/t_w | $2.45 \sqrt{E/F_y}$ | Beams in SMF (SEISMIC 9) |
| | Webs in flexural compression or combined flexural and axial compression |  | 10 | h/t_w | If $C_a \leq 0.125$ $3.14 \sqrt{\frac{E}{F_y}} (1 - 1.54C_a)$ If $C_a > 0.125$ $1.12 \sqrt{\frac{E}{F_y}} (2.33 - C_a) \geq 1.49 \sqrt{\frac{E}{F_y}}$ | Beams in BRBF (SEISMIC 16) Columns in SMF (SEISMIC 9) Columns in SCBF (SEISMIC 13) Columns in EBF (SEISMIC 15) Columns in BRBF (SEISMIC 16) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |

Table 4-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

| Section Type | Description of Element | Graphical Example | Given Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Elements | Applicable Situation with Code Reference |
|----------------|---|-------------------|----------------|------------------------------------|--|---|
| | | | | | Seismically Compact (λ_{ps}) | |
| Double Channel | Flexural or Uniform compression in flanges | | 4 | b_f/t_f | $0.30\sqrt{E/F_y}$ | Columns in SCBF (SEISMIC 13) Braces in SCBF (SEISMIC 13) |
| | Flexure compression in beam web | | 9 | h/t_w | $2.45\sqrt{E/F_y}$ | Beams in SMF (SEISMIC 9) |
| | Webs in flexural compression or combined flexural and axial compression | | 10 | h/t_w | If $C_a \leq 0.125$ $3.14\sqrt{\frac{E}{F_y}}(1 - 1.54C_a)$ If $C_a > 0.125$ $1.12\sqrt{\frac{E}{F_y}}(2.33 - C_a) \geq 1.49\sqrt{\frac{E}{F_y}}$ | Beams in BRBF (SEISMIC 16) Columns in SMF (SEISMIC 9) Columns in SCBF (SEISMIC 13) Columns in EBF (SEISMIC 15) Columns in BRBF (SEISMIC 16) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |
| Box | Flexural or axial compression of flanges under major axis bending | | 12 | b/t | $0.64\sqrt{E/F_y}$ | Columns in SCBF (SEISMIC 13) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |
| | Flexural compression of webs under minor axis bending | | 12 | h/t | $0.64\sqrt{E/F_y}$ | Columns in SCBF (SEISMIC 13) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |
| T Shape | Flexural or axial compression in flanges | | 7 | $b_f/2t_f$ | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |
| | Compression in stems | | 8 | d/t_w | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |
| Double Angle | Any type of compression in leg | | 7 | b/t | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |
| | Any type of compression in leg | | 7 | b/t | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |

Table 4-1 Limiting Width-Thickness Ratios of Compression Elements for Classification Sections

| Section Type | Description of Element | Graphical Example | Given Case No. | Width-Thickness Ratio, (λ) | Limiting Width-Thickness Ratios for Compression Elements | |
|--------------|------------------------------------|--|----------------|--------------------------------------|--|--|
| | | | | | Seismically Compact (λ_{ps}) | Applicable Situation with Code Reference |
| Angle | Any type of compression in any leg |  | 7 | b/t | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |
| | Any type of compression in any leg |  | 7 | b/t | $0.30\sqrt{E/F_y}$ | Chord of STMF (SEISMIC 12) |
| Pipe | Flexural or axial compression |  | 11 | D/t | $0.044 \frac{E}{F_y}$ | Columns in SCBF (SEISMIC 13) Braces in SCBF (SEISMIC 13) Braces in OCBF (SEISMIC 14) |
| Round Bar | ----- | ----- | --- | ----- | Assumed non-compact | |
| Rectangular | Any compression |  | 6 | b/t | 2.5 | Diagonal web member in STMF (SEISMIC 12) |
| General | ----- | ----- | --- | ----- | Assumed non-compact | |
| SD Section | ----- | ----- | --- | ----- | Assumed non-compact | |

The table uses the dimension-related variables, such as b_f , t_f , t_w , b , t , h , D , and so forth. Some of those variables have been explained in the table itself. Some are explained in Figure 3-1 and also explained in the code (AISC B4.1, B4.2, Table B4.1). The variable C_a can be expressed as follows:

$$C_a = \begin{cases} P_u / (\phi_b P_y) & \text{for LRFD} \\ \Omega_b P_a / P_y & \text{for ASD} \end{cases} \quad (\text{AISC SEISMIC Table I-8-1 Note K})$$

where,

P_a = Required compressive strength (ASD)

P_u = Required compressive strength (LRFD)

P_y = Axial yield strength

$$\phi_b = 0.90$$

$$\Omega_b = 1.67$$

When satisfying the Special Seismic criteria, it is in general not necessary for the design sections to be Seismically Compact (AISC SEISMIC 8.2). However, for certain special cases, the design sections must be Seismically Compact (AISC SEISMIC 8.2b) or Compact (AISC SEISMIC 8.2a, AISC Table B4.1) as described in the "Seismic Requirements" section of this chapter. For a situation when the code requires the design section to be Seismically Compact, but the section fails to satisfy the criteria, the user must modify the section. In that case, the program issues an error message in the output.

4.8 Special Check for Column Strength

When $P_u/\phi_c P_n$ for LRFD provision or $\Omega_c P_a/P_n$ for ASD provision in columns due to prescribed loading combination without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in the absence of any applied moment and shear for the amplified seismic load combinations (AISC SEISMIC 8.3(1), 4.1).

For LRFD provisions,

$$(0.9 - 0.2S_{DS})DL \pm \Omega_0 Q_E \quad (\text{ASCE 12.4.3.2, 2.3.2-7})$$

$$(1.2 + 0.2S_{DS})DL \pm \Omega_0 Q_E + 1.0LL \quad (\text{ASCE 12.4.3.2, 2.3.2-5})$$

For ASD provisions,

$$(1.0 + 0.14S_{DS})DL \pm 0.7\Omega_0 Q_E \quad (\text{ASCE 12.4.3.2, 2.4.1-5})$$

$$(1.0 + 0.105S_{DS})DL \pm 0.7(0.7\Omega_0)Q_E + 0.75LL \quad (\text{ASCE 12.4.3.2, 2.4.1-6})$$

$$(0.6 - 0.14S_{DS})DL \pm 0.7\Omega_0 Q_E \quad (\text{ASCE 12.4.3.2, 2.4.1-7})$$

where Ω_0 and S_{DS} are as described in the "Design Load Combinations" section in Chapter 3.

The preceding load combinations are used to calculate axial force only because other forces and moments are ignored. This axial capacity check is in addition to regular strength checks for the regularly specified load combinations (AISC SEISMIC 8.3).

Those combinations involving Ω_0 are internal to the program. The user does NOT need to create additional load combinations for such load combinations. The special circumstances for which these load combinations are additionally checked are described later in this chapter, as appropriate. The special loading combination factors are applied directly to the load cases. It is assumed that any required scaling (such as may be required to scale response spectra results) has already been applied to the load cases.

If the overwrite item "Ignore Special Seismic Load?" is set to yes, the preceding check will not be performed.

4.9 Member Design

This section describes the special requirements for designing a member. The section has been divided into subsections for each framing type.

4.9.1 Special Moment Frames (SMF)

For this framing system, the following additional requirements are checked or reported (AISC SEISMIC 9).

- When $P_u/\phi_c P_n$ (or $\Omega_c P_a/P_n$ in ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in absence of any applied moment and shear for the *special seismic load combination* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- All beams and columns are required to be Seismically Compact (AISC SEISMIC 9.4a, 8.2b, Table I-8-1). The limits of the width-thickness ratio, λ_{ps} , has been presented in this manual in Table 4-1. If these criteria are satisfied, the section is reported as SEISMIC as described earlier under the "Classification of Sections for

Local Buckling" section. If these criteria are not satisfied, the program issues an error message.

- The program checks the slenderness ratio, L/r , for columns to be less than 60 (AISC SEISMIC 9.7b(2)). If this criterion is not satisfied, the program issues an error message.
- The program checks the laterally unsupported length of beams not to exceed $0.086(E/F_y)r_y$ (AISC SEISMIC 9.8). If this criterion is not satisfied, the program issues an error message.

4.9.2 Intermediate Moment Frames (IMF)

For this framing system, the following additional requirements are checked and reported (AISC SEISMIC 10).

- When $P_u/\phi_c P_n$ (or $\Omega_c P_a/P_n$ in ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- All beams and columns are checked to be Compact (AISC SEISMIC 10.4a, 8.2a, AISC Table B4.1). The limits of the width-thickness ratio, λ_p , have been presented in this manual in Table 3-5. If this criterion is satisfied, the section is reported as Compact as described earlier under the "Classification of Sections for Local Buckling" section in Chapter 3. If this criterion is not satisfied, the program issues an error message.
- The program checks the laterally unbraced length of beams between lateral braces not to exceed the limiting value $0.17(E/F_y)r_y$ (AISC SEISMIC 10.8). If this criterion is not satisfied, the program issues an error message.

4.9.3 Ordinary Moment Frames (OMF)

For this framing system, the following additional requirement is checked and reported (AISC SEISMIC 11).

- When $P_u/\phi_c P_n$ (or $\Omega_c P_a/P_n$ for ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).

4.9.4 Special Truss Moment Frames (STMF)

No special consideration for this type of framing system is given by the program. The user is required to check the seismic design requirements for STMF independently.

4.9.5 Special Concentrically Braced Frames (SCBF)

For this framing system, the following additional requirements are checked or reported (AISC SEISMIC 13).

- When $P_u\phi_c/P_n$ (or $\Omega_c P_a/P_n$ for ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in the absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- All column and brace members are checked to be Seismically Compact according to Table 4-1 (AISC SEISMIC 13.2d, 8.2b, Table I-8-1). If these criteria are satisfied, the section is reported as SEISMIC as described earlier under "Classification of Sections for Local Buckling" in this chapter. If these criteria are not satisfied, the program issues an error message.
- The maximum Kl/r ratio of the braces is checked not to exceed $4\sqrt{E/F_y}$ (AISC SEISMIC 13.2a). If this criterion is not satisfied, the program issues an error message.

The program checks the following requirements for V-type or inverted V-type SCBF frames.

- The program checks the laterally unbraced length of beams between lateral braces not to exceed the limiting value of L_{pd} (AISC SEISMIC 13.4a(2)). The expression for L_{pd} for Box and Solid rectangular sections is given as follows:

$$L_{pd} = \left[0.17 + 0.10 \left(\frac{M_1}{M_2} \right) \right] \left(\frac{E}{F_y} \right) r_y \geq 0.1 \left(\frac{E}{F_y} \right) r_y.$$

(AISC A-1-8, AISC SEISMIC 13.4a(2))

For all other sections, L_{pd} is take as follows:

$$L_{pd} = \left[0.12 + 0.076 \left(\frac{M_1}{M_2} \right) \right] \left(\frac{E}{F_y} \right) r_y,$$

(AISC A-1-7, AISC SEISMIC 13.4a(2))

where,

M_1 = Smaller moment at the end of the unbraced length of beam,

M_2 = Larger moment at the end of the unbraced length of the beam,

r_y = Radius of gyration about minor axis.

M_1/M_2 is positive for reverse curvature bending and negative for single curvature bending (AISC A1.7).

Note: Beams intersected by chevron (V or inverted-V) braces are NOT currently checked to have a strength to support loads for the following two conditions (AISC SEISMIC 13.4a):

- (a) A beam that is intersected by braces shall be designed to support the effects of all tributary dead and live loads from load combinations stipulated by the code, assuming the bracings are not present.
- (b) A beam that is intersected by braces and supporting earthquake load shall be designed to resist the effects of the load combinations stipulated by the code, except the brace forces have to be replaced by their capacities. The forces in all braces in tension shall be assumed to be equal to $R_y F_y A_g$ (AISC SEISMIC 13.4a(1)a). The forces in all braces in compression shall be assumed to be equal to $0.3 P_n$ (AISC SEISMIC 13.4a(1)b).

4.9.6 Ordinary Concentrically Braced Frames (OCBF)

For this framing system, the following additional requirements are checked or reported (AISC SEISMIC 14).

- When $P_u \phi_c / P_n$ (or $\Omega_c P_a / P_n$ for ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in the absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- All brace members are checked to be Seismically Compact according to Table 4-1 (AISC SEISMIC 14.2, 8.2b, Table I-8-1). If the criteria are satisfied, the section is reported as SEISMIC as described earlier in "Classification of Sections for Local Buckling" in this chapter. If this criterion is not satisfied, the program issues an error message.
- The program checks the laterally unbraced length of beams for V or inverted V configurations between lateral braces not to exceed the limiting value of L_{pd} (AISC SEISMIC 14.3(2)). The expression for L_{pd} for Box and Solid rectangular sections is given as follows:

$$L_{pd} = \left[0.17 + 0.10 \left(\frac{M_1}{M_2} \right) \right] \left(\frac{E}{F_y} \right) r_y \geq 0.1 \left(\frac{E}{F_y} \right) r_y.$$

(AISC A-1-8, AISC SEISMIC 14.3(2))

For all other sections, L_{pd} is take as follows:

$$L_{pd} = \left[0.12 + 0.076 \left(\frac{M_1}{M_2} \right) \right] \left(\frac{E}{F_y} \right) r_y,$$

(AISC A-1-7, AISC SEISMIC 14.3(2))

where,

M_1 = Smaller moment at the end of the unbraced length of beam,

M_2 = Larger moment at the end of the unbraced length of the beam,

r_y = Radius of gyration about minor axis.

M_1/M_2 is positive for reverse curvature bending and negative for single curvature bending (AISC A1.7).

- The maximum Kl/r ratio of the braces for V or inverted-V configurations is checked not to exceed $4.0\sqrt{E/F_y}$ (AISC SEISMIC 14.2). If this criterion is not met, an error message is reported in the output.

4.9.7 Ordinary Concentrically Braced Frames from Isolated Structures (OCBFI)

For this framing system, the following additional requirements are checked or reported (AISC SEISMIC 14.5).

- When $P_u/\phi_c P_n$ (or $\Omega_c P_a/P_n$ in ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- All braces are required to be Compact (AISC SEISMIC 14.5a, 8.2a, AISC Table B4.1). The limits of the width-thickness ratio, λ_p , have been presented in this manual in Table 3-5. If these criteria are satisfied, the section is reported as Compact as described previously under the "Classification of Sections for Local Buckling" section in Chapter 3. If this criterion is not satisfied, the program issues an error message.
- The maximum Kl/r ratio for the braces is checked not to exceed $4\sqrt{E/F_y}$ (AISC SEISMIC 14.5a). If this criterion is not met, an error message is reported in the output.

4.9.8 Eccentrically Braced Frames (EBF)

For this framing system, the program looks for and recognizes the eccentrically braced frame configurations shown in Figure 4-1. The following additional requirements are checked or reported for the beams, columns and braces associated with these configurations (AISC SEISMIC 15).

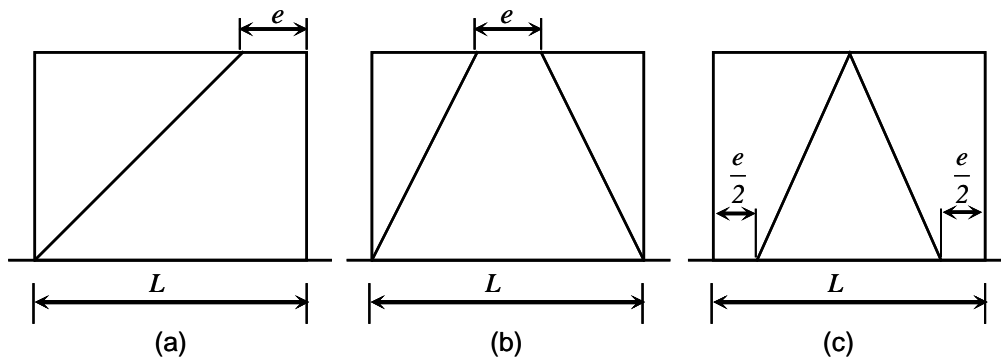


Figure 4-1. Eccentrically Braced Frame Configurations

- When $P_u\phi_c/P_n$ (or $\Omega_c P_a/P_n$ for ASD) in columns due to prescribed loading combinations without consideration of amplified seismic load is greater than 0.4, the axial compressive and tensile strengths are checked in absence of any applied moment and shear for the *special seismic load combinations* as described previously in the "Special Check for Column" section of this manual (AISC SEISMIC 8.3, 4.1).
- The beams are checked to be Seismically Compact according to Table 4-1 (AISC SEISMIC 15.2a, 8.2b, Table I-8-1). If this criterion is satisfied, the section is reported as SEISMIC as described earlier under "Classification of Sections for Local Buckling Section" in this chapter. If this criterion is not satisfied, the program issues an error message.
- The shear strength for link beams is taken as follows (AISC SEISMIC 15.2b):

$$V_u \leq \phi_v V_n \text{ (LRFD) or} \quad \text{(AISC SEISMIC 15.2b)}$$

$$V_a \leq V_n / \Omega_v \text{ (ASD),} \quad \text{(AISC SEISMIC 15.2b)}$$

where,

$$V_n = \min(V_{pa}, 2M_{pa} / e) \quad (\text{AISC SEISMIC 15.2b})$$

$$V_{pa} = V_p \sqrt{1 - \left(\frac{P_r}{P_c}\right)^2} \quad (\text{AISC SEISMIC 15-1})$$

$$M_{pa} = 1.18M_p \left[1 - \frac{P_r}{P_c}\right], \quad (\text{AISC SEISMIC 15-2})$$

$$V_p = 0.6F_y(d - 2t_f)t_w, \quad (\text{AISC SEISMIC 15.2b})$$

$$M_p = ZF_y \quad (\text{AISC SEISMIC 15.2b})$$

$$\phi = \phi_v \text{ (default is 0.9)} \quad (\text{AISC SEISMIC 15.2b})$$

$$\Omega = \Omega_v \text{ (default is 1.67)} \quad (\text{AISC SEISMIC 15.2b})$$

$$P_r = P_u \text{ (LRFD)} \quad (\text{AISC SEISMIC 15.2b})$$

$$P_r = P_a \text{ (ASD)} \quad (\text{AISC SEISMIC 15.2b})$$

$$P_c = P_y \text{ (LRFD)} \quad (\text{AISC SEISMIC 15.2b})$$

$$P_c = P_y / 1.5 \text{ (ASD)} \quad (\text{AISC SEISMIC 15.2b})$$

$$P_y = A_g F_y. \quad (\text{AISC SEISMIC 15.2b})$$

- If $P_u > 0.15A_g F_y$ (LRFD) or $P_a > (0.15/1.5)A_g F_y$ (ASD), the link beam length, e , is checked not to exceed the following:

$$\text{– if } \rho' \frac{A_w}{A_g} \geq 0.3$$

$$e \leq \left[1.15 - 0.5\rho' \frac{A_w}{A_g} \right] \left[1.6 \frac{M_p}{V_p} \right] \quad (\text{AISC SEISMIC 15-3})$$

$$- \text{ if } \rho' \frac{A_w}{A_g} < 0.3$$

$$e \leq \left[1.6 \frac{M_p}{V_p} \right] \quad (\text{AISC SEISMIC 15-4})$$

where,

$$A_w = (d - 2t_f)t_w \quad (\text{AISC SEISMIC 15.2b})$$

$$\rho' = P_r / V_r \quad (\text{AISC SEISMIC 15.2b})$$

$$V_r = V_u \text{ (LRFD)} \quad (\text{AISC SEISMIC 15.2b})$$

$$V_r = V_a \text{ (ASD)} \quad (\text{AISC SEISMIC 15.2b})$$

If the check is not satisfied, the program reports an error message.

- The link beam rotation, θ , of the individual bay relative to the rest of the beam is calculated as the story drift Δ times bay length (L) divided by the total lengths of link beams (e) in the bay.

The link rotation, θ , is checked as follows (AISC SEISMIC 15.2c):

$$\theta = \frac{\Delta L}{e}$$

- $\theta \leq 0.08$ radian, where link beam clear length, $e \leq 1.6 M_p / V_p$
- $\theta \leq 0.02$ radian, where link beam clear length, $e \geq 2.6 M_p / V_p$
- $\theta \leq$ value interpolated between 0.08 and 0.02 as the link beam clear length varies from $1.6 M_p / V_p$ to $2.6 M_p / V_p$.

The story drift is calculated as

$$\Delta = \frac{\Delta_s C_d}{I}, \quad (\text{ASCE 12.8-15})$$

where C_d is a System Deflection Amplification Factor and I is the system Importance Factor.

- The beam strength outside the link is checked to be at least $1.1R_y$ times the beam force corresponding to the controlling link beam shear strength (AISC SEISMIC 15.6b). The controlling link beam nominal shear strength is taken as follows:

$$V_n = \min(V_{pa}, 2M_{pa}/e). \quad (\text{AISC SEISMIC 15.6, 15.2})$$

The values of V_{pa} and M_{pa} are calculated following the procedure described previously (AISC SEISMIC 15.2). The correspondence between brace force and link beam force is obtained from the associated load cases, whichever has the highest link beam force of interest.

For load combinations including seismic effects, a load Q_l is substituted for the term E , where Q_l is defined as the axial forces and moments generated by at least 1.1 times the expected nominal shear strength $R_y V_n$ (AISC SEISMIC 15.6b).

- All braces are checked to be at least Compact (AISC SEISMIC 15.6a, 8.2a, AISC Table B4.1). The limits of the width-thickness ratio, λ_p , have been presented in this manual in Table 3-5. If this criterion is satisfied, the section is reported as Compact as described earlier under the "Classification of Sections for Local Buckling" section in Chapter 3. If this criterion is not satisfied, the program issues an error message.
- The brace strength is checked for $1.25R_y$ times the brace forces corresponding to the controlling link beam nominal shear strength amplified by $R_y (R_y V_n)$ (AISC SEISMIC 15.6a). The controlling link beam nominal shear strengths are obtained by the process described earlier (AISC SEISMIC 15.2b).

For load combinations including seismic effects, a load Q_{vl} is substituted for the term E , where Q_l is defined as axial forces and moments generated by at least 1.25 times the expected nominal shear strength of the link $R_y V_n$ (AISC SEISMIC 15.6a).

- All column members are checked to be Seismically Compact according to Table 4-1 (AISC SEISMIC 15.8, 8.2b, Table I-8-1). If these criteria are satisfied, the section is reported as SEISMIC as described earlier under the "Classification of

Sections for Local Buckling" in this chapter. If these criteria are not satisfied, the program issues an error message.

- The column strength is checked for $1.1R_y$ times the column forces corresponding to the controlling link beam nominal shear strength (AISC SEISMIC 15.8). The controlling link beam nominal shear strength and the corresponding forces are obtained by the process described previously.

Note: Axial forces in the beams are included in checking the beams. The user is reminded that using a rigid diaphragm model will result in zero axial forces in the beams. The user must disconnect some of the column lines from the diaphragm to allow beams to carry axial loads. It is recommended that only one column line per eccentrically braced frame be connected to the rigid diaphragm or that a flexible diaphragm model be used.

4.9.9 Buckling Restrained Braced Frames (BRBF)

No special consideration for this type of framing system is given by the program. The user is required to check the seismic design requirements for BRBF independently.

4.9.10 Special Plate Shear Walls (SPSW)

No special consideration for this type of framing system is given by the program. The user is required to check the seismic design requirements for SPSW independently.

4.10 Joint Design

When using the SEISMIC design code, the structural joints are checked and designed for the following.

- Check the requirement of continuity plate and determination of its area
- Check the requirement of doubler plate and determination of its thickness
- Check the ratio of beam flexural strength to column flexural strength
- Report the beam connection shear

- Report the brace connection force

4.10.1 Design of Continuity Plates

In a plan view of a beam-column connection, a steel beam can frame into a column in the following ways.

- The steel beam frames in a direction parallel to the column major direction, i.e., the beam frames into the column flange.
- The steel beam frames in a direction parallel to the column minor direction, i.e., the beam frames into the column web.
- The steel beam frames in a direction that is at an angle to both of the principal axes of the column, i.e., the beam frames partially into the column web and partially into the column flange.

To achieve a proper beam-column moment connection strength, continuity plates such as shown in Figure 2.3 of Chapter 2 are usually placed on the column, in line with the top and bottom flanges of the beam, to transfer the compression and tension flange forces of the beam into the column. For connection conditions described by the first bullet, where the beam frames into the flange of the column, such continuity plates are not always needed. The requirement depends on the magnitude of the beam-flange force and the properties of the column. This is the condition that the program investigates. Columns of I Sections only are investigated. The program evaluates the continuity plate requirements for each of the beams that frame into the column flange (i.e., parallel to the column major direction) and reports the maximum continuity plate area that is needed for each beam flange. The continuity plate requirements are evaluated for moment frames (OMF, IMF, SMF) only. No check is made for braced frames (OCBE, SCBF, EBF, BRBF).

The program first evaluates the need for continuity plates. When the required strength P_{bf} exceeds the available strength ϕR_n (LRFD) or R_n/Ω (ASD), as appropriate, a continuity plate will be required. The program checks the following limit states.

- The column flange design strength, ϕR_n , and the allowable strength, R_n/Ω , for the limit state of flange local bending is given as follows:

$$R_n = 6.25t_{fc}^2 F_{yc} \quad \text{if not at top story} \quad (\text{AISC J10-1})$$

$$R_n = (0.5)6.25t_{fc}^2 F_{yc} \quad \text{if at top story} \quad (\text{AISC J10.1})$$

where

$$\phi = 0.9 \text{ (LRFD)}$$

$$\Omega = 1.67 \text{ (ASD)}$$

- The available strength of the column web against local yielding at the toe of the fillet is given as follows:

$$R_n = (5.0k_c + t_{fb})F_{yc}t_{wc} \quad \text{if not at top story} \quad (\text{AISC J10-2})$$

$$R_n = (2.5k_c + t_{fb})F_{yc}t_{wc} \quad \text{if at top story} \quad (\text{AISC J10-3})$$

where

$$\phi = 1.0 \text{ (LRFD)}$$

$$\Omega = 1.5 \text{ (ASD)}$$

- The available strength of the column web against crippling is given as follows:

$$R_n = 0.80t_{wc}^2 \left[1 + 3 \left(\frac{t_{fb}}{d_c} \right) \left(\frac{t_{tw}}{t_{fc}} \right)^{1.5} \right] \sqrt{\frac{EF_{yc}t_{fc}}{t_{wc}}}, \quad \text{if not at top story} \quad (\text{AISC J10-4})$$

$$R_n = 0.40t_{wc}^2 \left[1 + 3 \left(\frac{t_{fb}}{d_c} \right) \left(\frac{t_{tw}}{t_{fc}} \right)^{1.5} \right] \sqrt{\frac{EF_{yc}t_{fc}}{t_{wc}}}, \quad \text{if at top story and } t_{fb}/d_c \leq 0.2 \quad (\text{AISC J10-5a})$$

$$R_n = 0.40t_{wc}^2 \left[1 + \left(4 \frac{t_{fb}}{d} - 0.2 \right) \left(\frac{t_{tw}}{t_{fc}} \right)^{1.5} \right] \sqrt{\frac{EF_{yw}t_{fc}}{t_{wc}}}, \quad (\text{AISC J10-5b})$$

where

$$\phi = 0.75 \text{ (LRFD)}$$

$$\Omega = 2.0 \text{ (ASD)}$$

- The available compressive strength of the column web against local buckling is given as follows:

$$R_n = \frac{24t_{wc}^3\sqrt{EF_{yc}}}{d_c}, \quad \text{if not at the top story} \quad \text{(AISC J10.8)}$$

$$R_n = \frac{12t_{wc}^3\sqrt{EF_{yc}}}{d_c}, \quad \text{if at the top story.} \quad \text{(AISC J10.8, J10.5)}$$

If any of the preceding conditions are not met, the program calculates the required continuity plate area as follows.

For LRFD:

$$A_{cp} = \frac{(P_{bf} - \phi R_n)}{\phi_c F_{cr}}, \quad \text{(AISC J10, J10.8, E3)}$$

For ASD:

$$A_{cp} = \frac{(P_{bf} - R_n/\Omega)}{F_{cr}/\Omega_c}, \quad \text{(AISC J10, J10.8, E3)}$$

In the preceding expressions, ϕ_c , Ω_c , and F_{cr} are taken as follows:

$$\phi_c = 0.90 \text{ (LRFD)} \quad \text{(AISC E1)}$$

$$\Omega_c = 1.67 \text{ (ASD)} \quad \text{(AISC E1)}$$

F_{cr} = Flexural buckling stress of equivalent column
related to the beam-column joint

The flexural buckling stress, F_{cr} , is determined as follows:

$$F_{cr} = \begin{cases} \left(0.658 \sqrt{\frac{F_y}{F_e}}\right) F_y, & \text{if } \frac{KL}{r} \leq 4.71 \sqrt{\frac{E}{F_y}}, \\ 0.877 F_e, & \text{if } \frac{KL}{r} > 4.71 \sqrt{\frac{E}{F_y}}, \end{cases} \quad (\text{AISC J10.8, E3})$$

where F_e is the elastic critical buckling stress given by

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}. \quad (\text{AISC E3-4})$$

The member properties of the equivalent column are taken as follows:

- The cross-section is comprised of two stiffeners and a strip of the web having a width of $25t_{wc}$ at the interior stiffener and $12t_{wc}$ at the ends of the columns (AISC J10.8).
- The effective length is taken as $0.75h$, i.e., $K = 0.75$ and $L = h = d_c - 2t_{fc}$ (AISC J10.8).
- $\frac{KL}{r}$ is calculated based on the equivalent cross-section and equivalent length stated here.

In addition to satisfying the preceding limit states, it is made sure that the equivalent section, consisting of the stiffeners and part of the web plate, is able to resist the compressive concentrated force (AISC J8). This is similar to a column capacity check. For this condition, the program calculates the required continuity plate area as follows:

For LRFD:

$$A_{cp} = \frac{P_{bf}}{\phi_c F_{cr}} - 25t_{wc}^2, \quad \text{if not at top story}$$

$$A_{cp} = \frac{P_{bf}}{\phi_c F_{cr}} - 12t_{wc}^2, \quad \text{if at top story} \quad (\text{AISC J10.8, E3})$$

For ASD:

$$A_{cp} = \frac{P_{bf}}{F_{cr}/\Omega_c} - 25t_{wc}^2, \quad \text{if not at top story}$$

$$A_{cp} = \frac{P_{bf}}{F_{cr}/\Omega_c} - 12t_{wc}^2, \quad \text{if at top story} \quad (\text{AISC J10.8, E3})$$

An iterative process is involved as A_{cp} , r , and F_{cr} are interdependent. If A_{cp} is needed, iteration starts with the minimum thickness and minimum width of the continuity plate. A maximum of three iterations is performed.

If $A_{cp} \leq 0$, no continuity plates are required. If continuity plates are required, they must satisfy a minimum area specification defined as follows:

- The minimum thickness of the stiffeners is taken as follows:

$$t_{cp}^{\min} = 0.5t_{fb} \quad (\text{AISC J10.8})$$

If the maximum thickness is more than the upper limit, the program reports an error. Here it is assumed that the continuity plate can extend for the full width of the column flange.

- The minimum width of the continuity plate on each side plus 1/2 the thickness of the column web shall not be less than 1/3 of the beam flange width, or

$$b_{cp}^{\min} = 2 \left(\frac{b_{fp}}{3} - \frac{t_{wc}}{2} \right) \quad (\text{AISC J10.8})$$

- So that the minimum area is given by

$$A_{cp}^{\min} = t_{cp}^{\min} b_{cp}^{\min}. \quad (\text{AISC J10.8})$$

Therefore, the continuity plate area provided by the program is zero or the greater of A_{cp} and A_{cp}^{\min} .

In the preceding equations,

A_{cp} = Required continuity plate area

F_{yc} = Yield stress of the column and continuity plate material

d_b = Beam depth

d_c = Column depth

h = Clear distance between flanges of column less fillets for rolled shapes

k_c = Distance between outer face of the column flange and web toe of its fillet

M_u = Factored beam moment

P_{bf} = Beam flange force, assumed as $M_u/(d_b - t_{fb})$

R_n = Nominal strength

t_{fb} = Beam flange thickness

t_{fc} = Column flange thickness

t_{wc} = Column web thickness

ϕ = Resistance factor (LRFD)

Ω = Safety factor (ASD)

The special seismic requirements additionally checked by the program are dependent on the type of framing used. Continuity plate requirements for seismic design are evaluated for moment frames (OMF, IMF, SMF) only. No checks are performed for braced frames (OCBF, SCBF, and EBF).

- For OMF, the continuity plates are checked and designed for a beam flange force,

$$P_{bf} = M_{pb}/(d_b - t_{fb}),$$

$$P_{bf} = M_{pb}/(d_b - t_{fb}) \quad (\text{AISC SEISMIC 11.5})$$

- For SMF and IMF, the continuity plates are checked and designed for a beam flange force, $P_{bf} = R_y F_y b_{fb} t_{fb}$,

$$P_{bf} = R_y F_y b_{fb} t_{fb} \quad (\text{AISC SEISMIC 9.5, 10.5})$$

Note that the code insists on designing the continuity plate to match with tested connection (AISC SEISMIC 9.5, 10.5, 11.5).

4.10.2 Design of Doubler Plates

One aspect of the design of a steel framing system is an evaluation of the shear forces that exist in the region of the beam-column intersection known as the panel zone.

Shear stresses seldom control the design of a beam or column member. However, in a Moment-Resisting frame, the shear stress in the beam-column joint can be critical, especially in framing systems when the column is subjected to major direction bending and the joint shear forces are resisted by the web of the column. In minor direction bending, the joint shear is carried by the column flanges, in which case the shear stresses are seldom critical, and this condition is therefore not investigated by the program.

Shear stresses in the panel zone, due to major direction bending in the column, may require additional plates to be welded onto the column web, depending on the loading and the geometry of the steel beams that frame into the column, either along the column major direction or at an angle so that the beams have components along the column major direction. See Figure 2-3 of Chapter 2. The program investigates such situations and reports the thickness of any required doubler plates. Only columns with I Shapes are investigated for doubler plate requirements. Also doubler plate requirements are evaluated for moment frames (OMF, IMF, SMF) only. No check is made for braced frames (OCBF, SCBF, EBF).

The program calculates the required thickness of doubler plates using the following algorithms. The shear force in the panel zone, is given by

$$V_p = \sum_{n=1}^{n_b} \frac{M_{bn} \cos \theta_n}{d_n - t_{fn}} - V_c.$$

The available strength of the web panel zone for the limit state of shear yielding is determined as ϕR_n (LRFD) or R_n/Ω (ASD), as appropriate. Assuming that the effect of panel zone deformation on frame stability has not been considered in analysis, the nominal strength, R_n , is determined as follows:

$$R_n = 0.6F_y d_c t_p, \quad \text{for } P_r \leq 0.4P_c, \text{ and} \quad (\text{LRFD J10-9})$$

$$R_n = 0.6F_y d_c t_p \left[1.4 - \frac{P_r}{P_c} \right], \quad \text{for } P_r > 0.4P_c. \quad (\text{LRFD J10-10})$$

By using $V_p = \phi R_n$ (LRFD) or $V_p = R_n/\Omega$ (ASD), as appropriate, the required column panel zone thickness t_p is found as follows.

For LRFD:

$$t_p = \frac{V_p/\phi}{0.6F_y d_c}, \quad \text{for } P_r \leq 0.4P_c$$

$$t_p = \frac{V_p/\phi}{0.6F_y d_c \left(1.4 - \frac{P_r}{P_c} \right)}, \quad \text{for } P_r > 0.4P_c.$$

For ASD:

$$t_p = \frac{\Omega V_p}{0.6F_y d_c}, \quad \text{for } P_r \leq 0.4P_c$$

$$t_p = \frac{\Omega V_p}{0.6F_y d_c \left(1.4 - \frac{P_r}{P_c} \right)}, \quad \text{for } P_r > 0.4P_c$$

The extra thickness, or the required thickness of the doubler plate is given as follows:

$$t_{dp} = t_p - t_w,$$

where

F_y = Column and doubler plate yield stress

t_p = Required column panel zone thickness

t_{fn} = Flange thickness of n -th beam

t_{dp} = Required doubler plate thickness

t_{fc} = Column flange thickness

t_w = Column web thickness

V_p = Required panel zone shear capacity k_c

V_c = Column shear in column above

n_b = Number of beams connecting to column

d_n = Overall depth of n -th beam connecting to column

θ_n = Angle between n -th beam and column major direction

d_c = Overall depth of column

M_{bn} = Factored beam moment from corresponding loading combination

R_n = Nominal shear strength of panel

P_r = Required axial strength, P_u (LRFD) or P_a (ASD)

P_y = Column axial yield strength, $F_y A$

P_c = P_y (LRFD) or $0.6F_y$ (ASD)

ϕ = 0.9 (LRFD)

Ω = 1.67 (ASD)

The largest calculated value of t_{dp} , calculated for any of the load combinations based on the factored beam moments and factored column axial loads, is reported.

Doubler plate requirements for seismic design are evaluated for SMF only. No further check/design is performed for other types of frames.

- For SMF, the panel zone doubler plate requirements that are reported will develop at least the beam moments equal to the expected plastic moment capacity of the beam ($R_y M_p$), or beam moments due to specified load combinations involving seismic load (AISC SEISMIC 9.3a). For seismic design, V_p is calculated using the equation given previously, except that M_{pb} is taken as $R_y F_y Z_{33}$.

The capacity of the panel zone in resisting this shear is taken as:

$$V_n = 0.60 F_y d_c t_p \left(1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_p} \right), \text{ for } P_u \leq 0.75 P_y \text{ (AISC J10-11)}$$

$$V_n = 0.60 F_y d_c t_p \left(1 + \frac{3b_{cf} t_{cf}^2}{d_b d_c t_p} \right) \left(1.9 - 1.2 \frac{P_r}{P_c} \right), \text{ for } P_r > 0.75 P_c \quad \text{(AISC J10-12)}$$

giving the required panel zone thickness as

$$t_p = \frac{V_p / \phi_v}{0.6 F_y d_c} - \frac{3b_{cf} t_{cf}^2}{d_b d_c}, \text{ if } P_r \leq 0.75 P_c$$

(AISC SEISMIC 9.3a, AISC J10-11)

$$t_p = \frac{V_p / \phi_v}{0.6 F_y d_c \left(1.9 - 1.2 \frac{P_r}{P_c} \right)} - \frac{3b_{cf} t_{cf}^2}{d_b d_c}, \text{ if } P_r > 0.75 P_c.$$

(AISC SEISMIC 9.3a, AISC J10-12)

In the preceding expression, the term V_p / ϕ_v is replaced by $\Omega_v V_p$ if the ASD provision is followed. The required doubler plate thickness is calculated as

$$t_{dp} = t_p - t_{wc}$$

where,

$$\phi = 1.0 \text{ (LRFD)} \quad \text{(AISC J10.6, SEISMIC 9.3a)}$$

$$\Omega = 1.50 \text{ (ASD)} \quad \text{(AISC J10.6, SEISMIC 9.3a)}$$

b_{cf} = width of column flange

t_{cf} = thickness of column flange

t_p = required column web thickness

d_b = depth of deepest beam framing into the major direction of the column

All other terms were explained previously.

- For SMF, the program checks the following panel zone column web thickness requirement:

$$t \geq \frac{(d_c - 2t_{fc}) + (d_b - 2t_{fb})}{90} \quad \text{(AISC SEISMIC 9.3b)}$$

Here, t is taken as $t_{wc} + t_{dp}$ when the doubler plate is plug welded to prevent local buckling. In such cases, t_{dp} is increased if necessary to meet this criterion. If the doubler plate is not plug welded to the web, t is taken as t_{wc} and also as t_{dp} for checking both the plates. If t_{wc} cannot satisfy the criteria, then a failure condition is declared. If t_{dp} does not satisfy this criterion, then its value is increased to meet the criteria. If the check is not satisfied, it is noted in the output.

4.10.3 Weak Beam Strong Column Measure

Only for Special Moment Frames (SMF) with seismic design category (SDC) A to F, the code requires that the sum of column flexure strengths at a joint should be more than the sum of beam flexure strengths (AISC SEISMIC 9.6). The column flexure strength should reflect the presence of axial force present in the column. The beam flexural strength should reflect potential increase in capacity for strain hardening. To facilitate the review of the strong column weak beam criterion, the program will report a beam-column plastic moment capacity ratio for every joint in the structure.

For the major direction of any column (top end), the beam-to-column-strength ratio is obtained as

$$R_{maj} = \frac{\sum_{n=1}^{n_b} M_{pbn}^* \cos \theta_n}{M_{pcax}^* + M_{pcb_x}^*}. \quad (\text{AISC SEISMIC 9.6})$$

For the minor direction of any column, the beam-to-column-strength ratio is obtained as

$$R_{maj} = \frac{\sum_{n=1}^{n_b} M_{pbn}^* \sin \theta_n}{M_{pcay}^* + M_{pcb_y}^*}, \quad (\text{AISC SEISMIC 9.6})$$

where,

R_{maj} = Plastic moment capacity ratios, in the major directions of the column

R_{min} = Plastic moment capacity ratios, in the minor directions of the column

M_{pbn}^* = Plastic moment capacity of n -th beam connecting to column

θ_n = Angle between the n -th beam and the column major direction

$M_{pcax,y}^*$ = Major and minor plastic moment capacities, reduced for axial force effects, of column above story level

$M_{pcb_x,y}^*$ = Major and minor plastic moment capacities, reduced for axial force effects, of column below story level

n_b = Number of beams connecting to the column

The plastic moment capacities of the columns are reduced for axial force effects and are taken as

$$M_{pc}^* = Z_c \left(F_{yc} - \left| \frac{P_{uc}}{A_g} \right| \right) \text{ (LRFD) (AISC SEISMIC 9.6)}$$

$$M_{pc}^* = Z_c \left[\left(\frac{F_{yc}}{1.5} \right) - \left| \frac{P_{uc}}{A_g} \right| \right] \text{ (ASD) (AISC SEISMIC 9.6)}$$

The plastic moment capacities of the beams are amplified for potential increase in capacity for strain hardening as

$$M_{pb}^* = 1.1 R_y F_{yb} Z_b f_{mv} \text{ (LRFD) (AISC SEISMIC 9.6)}$$

$$M_{pb}^* = \left(\frac{1.1}{1.5} \right) R_y F_{yb} Z_b f_{mv}, \text{ (ASD) (AISC SEISMIC 9.6)}$$

where,

Z_b = Plastic modulus of beam

Z_c = Plastic modulus of column

F_{yb} = Yield stress of beam material

F_{yc} = Yield stress of column material

P_{uc} = Axial compression force in column for given load combination

A_g = Gross area of column

f_{mv} = The moment amplification factor. It is taken as the ratio of beam moment at the centerline of column to the moment of the column face. This factor takes care of the M_{iw} (LRFD) or M_{av} (ASD) of the code (AISC SEISMIC 9.6). f_{mv} is taken as follows:

$$f_{mv} = 1 + \frac{d_c}{L_b} \text{ where,}$$

d_c = Depth of column section, and

$$L_b = \text{clear span length of the beam.}$$

For the preceding calculations, the section of the column above is taken to be the same as the section of the column below, assuming that the column splice will be located some distance above the story level.

4.10.4 Evaluation of Beam Connection Shears

For each steel beam in the structure, the program will report the maximum major shears at each end of the beam for the design of the beam shear connections. The beam connection shears reported are the maxima of the factored shears obtained from the loading combinations.

For special seismic design, the beam connection shears are not taken less than the following special values for different types of framing. The special seismic requirements additionally checked by the program are dependent on the type of framing used and the Seismic Design Category.

- For SMF, the beam connection shear is taken as the maximum of those from regular load combinations and those required for the development of full plastic moment capacity of the beam. The connection shear for the development of the full plastic moment capacity of beam is as follows:

$$V_u = \frac{CM_{pb}}{L_n} + V_{DL} + V_{LL} \text{ (LRFD),} \quad \text{(AISC SEISMIC 9.2a(3))}$$

$$V_a = (0.7) \frac{CM_{pb}}{L_n} + V_{DL} + V_{LL} \text{ (ASD),} \quad \text{(AISC SEISMIC 9.2a(3))}$$

where,

V = Shear force corresponding to END I or END J or beam

C = 0 if beam ends are pinned, or for cantilever beam
= 1 if one end of the beam is pinned
= 2 if no ends of the beam are pinned

M_{pb} = Plastic moment capacity of beam = $1.1 R_y M_p$

L_h = Clear length of the beam

V_{DL} = Absolute maximum of the calculated beam shears at the corresponding beam ends from the factored dead load only

V_{LL} = Absolute maximum of the calculated beam shears at the corresponding beam ends from the factored live load only

- For IMF, the beam connection shear is taken as the minimum of the two values: (a) maximum shear from the load combinations and (b) maximum shear based on beam moment capacity of the beam (AISC SEISMIC 10.2a(2)).

The maximum shear from the load combinations is determined from all of the regular load combinations and also from the *amplified seismic load combinations* (AISC SEISMIC 10.2a(2), ASCE 14.4.3). For LRFD or ASD provisions, appropriate load combinations are considered. The load combination for amplified seismic load combinations are also described previously in the "Design Loading Combinations" section.

The maximum shear based on beam moment capacity is calculated for any load combination involving seismic load by replacing the seismic effect on shear force with the capacity shear as follows:

$$V_u = \frac{CM_{pb}}{L_h} + V_{DL} + V_{LL} \text{ (LRFD)}, \quad \text{(AISC SEISMIC 10.2a(2))}$$

$$V_a = (0.7) \frac{CM_{pb}}{L_h} + V_{DL} + V_{LL} \text{ (ASD)}. \quad \text{(AISC SEISMIC 10.2a(2))}$$

All parameters in the preceding equation have been described previously in this section.

- For OMF, the beam connection shear is taken as the minimum of the two values: (a) maximum shear from the load combinations and (b) maximum shear based on beam moment capacity of the beam (AISC SEISMIC 11.2a(4)).

The maximum shear from the load combinations is determined from all of the regular load combinations and also from the *amplified seismic load combinations* (AISC SEISMIC 11.2a(4), ASCE 14.4.3). For LRFD or ASD provisions, appropriate load combinations are considered. The load combination for amplified

seismic load combinations also are described previously in the "Design Loading Combinations" section.

The maximum shear based on beam moment capacity is calculated for any load combination involving seismic load by replacing the seismic effect on shear force with the capacity shear as follows:

$$V_u = \frac{CM_{pb}}{L_h} + V_{DL} + V_{LL} \text{ (LRFD)}, \quad \text{(AISC SEISMIC 11.2a(4))}$$

$$V_a = (0.7) \frac{CM_{pb}}{L_h} + V_{DL} + V_{LL} \text{ (ASD)}. \quad \text{(AISC SEISMIC 11.2a(4))}$$

All parameters in the preceding equation have been described previously in this section. The moment connection is assumed to be FR.

- For SCBF the beam connection shear is taken as the maximum of those from regular load combination and those from *amplified seismic load combinations*.
- For OCBF and OBFI, the beam connection shear is taken as the maximum of those from regular load combinations and those from *amplified seismic load combinations*.
- For EBF, the beam connection shear is taken as the minimum of the two values: (a) maximum shear from the load combinations and (b) maximum shear based on link beam shear capacity (AISC SEISMIC 15.7, 11.2a(4)).

The maximum shear from the load combinations is determined from all of the regular load combinations and also from the *amplified seismic load combinations* (AISC SEISMIC 15.7, 11.2a(4), ASCE 14.2.3). For LRFD or ASD, appropriate load combinations are considered. The load combinations for amplified seismic load combinations also were described previously in the "Design Loading Combination" section of this chapter.

The maximum beam connection shear based on link beam shear capacity is taken as the beam connection shear that can be developed when the link beam yields in shear. The load factor for the seismic component of the load in the combination is calculated to achieve forces related to yielding of the link beam. For connection shear determination, the forces are further amplified by $1.1 R_y$ (AISC SEISMIC 15.7, 11.2a(4)).

If the beam-to-column connection is modelled with a pin in the program by releasing the beam end, it automatically affects the beam connection shear.

4.10.5 Evaluation of Brace Connection Forces

For each steel brace in the structure, the program reports the maximum axial force at each end of the brace for the design of the brace-to-beam connections. The brace connection forces reported are the maxima of the factored brace axial forces obtained from the loading combinations.

For special seismic design, the brace connection forces are not taken less than the following special values for different types of framing. The special seismic requirements additionally checked by the program are dependent on the type of framing used.

Bracer axial forces for seismic designs are evaluated for braced frames (SCBF, IOBF, OCBF, EBF) only. No special checks are performed for moment frames (OMF, IMF, SMF).

- For SCBF, the bracing connection force is taken as the minimum of the two values (AISC SEISMIC 13.3a):

The expected yield strength in tension of the bracing member, determined as $R_y F_y A_g$ (LFRD) or $R_y F_y A_g / 1.5$ (ASD), as appropriate (AISC SEISMIC 13.3a(a)).

The maximum load effect of the *amplified seismic load combination* (AISC SEISMIC 13.3a(b)).

Note that the required bracing connection force for the required compressive strength of the brace based on limit state of buckling that is equal to $1.1 R_y P_n$ (LFRD) or $(1.1/1.5) R_y P_n$ (ASD), as appropriate (AISC SEISMIC 13.3c), is always less than the corresponding value considered in case (a). So this limit state is not considered.

- For OCBF or OCBFI, the bracing connection force is taken as the minimum of the two values (AISC SEISMIC 14.4):
 - a. The expected yield strength in tension of the bracing member, determined as $R_y F_y A_g$ (LFRD) or $R_y F_y A_g / 1.5$ (ASD), as appropriate (AISC SEISMIC 14.4(2)).
 - b. The maximum load effect of the amplified seismic load combination (AISC SEISMIC 14.4 Exception (b)).
- For EBF, the required strength of the diagonal brace connection at both ends of the brace is taken as the maximum of the following two values: (a) the maximum connection force from the design load combinations, and (b) the maximum brace connection force based on the link beam shear capacity (AISC SEISMIC 15.6c, and 15.6a).

The maximum connection force from the load combinations is determined for all the regular load combinations. The amplified seismic load combinations are not considered.

The maximum brace connection force based on link beam shear capacity is taken as the brace connection force that can be developed when the link beam yields in shear. The load factor for seismic component of the load in the combination is calculate to achieve forces related to yielding of the link beam. For connection force determination, the forces are further amplified by $1.25R_y$ (AISC SEISMIC 15.6e, 15.6a).

Chapter 5 Design Output

The program has the capacity to create design output in four major ways – graphical display, file output, tabular display, and member specific detailed design information. The graphical display includes input and output design information for members visible in the active window; the display can be sent directly to a printer or saved to a file. The file output includes both summary and detail design data that can be saved in RTF, HTML and plain text formats. The tabular display output includes both summary and detail design data that can be displayed or saved in many formats, including Excel, Access, RTF, HTML and plain text. The member specific detailed design information shows the details of the calculation.

The following sections describe some of the typical graphical display, file output, tabular display output, and member specific detailed design information. Some of the design information is very specific to the chosen steel design code. This manual addresses "AISC 360-05/IBC 2006" design code related output information only.

5.1 Graphical Display of Design Information

The graphical display of design output includes input and output design information for all steel frame members that are visible in the active window. The

graphical output can be produced in color or in gray-scaled screen display. The active screen display can be sent directly to the printer or saved to a file in several formats.

Design input data displayed includes the following items for the "AISC 360-05/IBC 2006" code, as shown in Figure 5-1:

- Design sections
- Design framing type
- Live load reduction factors
- Unbraced length ratios, L factors, for major and minor direction of bending, and for lateral-torsional buckling
- Effective length factor for non-sway condition, K_1 factors, for major and minor directions of bending
- Effective length factor for sway condition, K_2 factors, for major and minor directions of bending
- Effective length factors, K_z , for lateral-torsional buckling
- C_m factors for major and minor directions of bending
- C_b factors for major and minor directions of bending
- B_1 factors for major and minor directions of bending
- B_2 factors for major and minor directions of bending

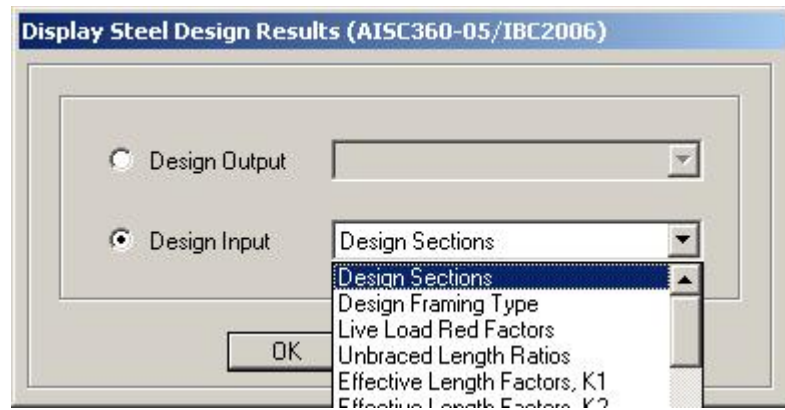


Figure 5-1 Choice of design input data for display on the model in the active window

- Ω_0 factors
- Yield stress, F_y
- Nominal axial capacities
- Nominal bending capacities
- Nominal shear capacities

Output design data plotted on the model includes the following items for the "ACI 360-05/IBC 2006" code as shown in Figure 5-2:

- P-M stress ratio values with members color-coded based on the ratio
- Shear stress ratio
- Continuity plate and doubler plate thickness
- Beam/column capacity ratios
- Beam connection shear force
- Brace connection axial force

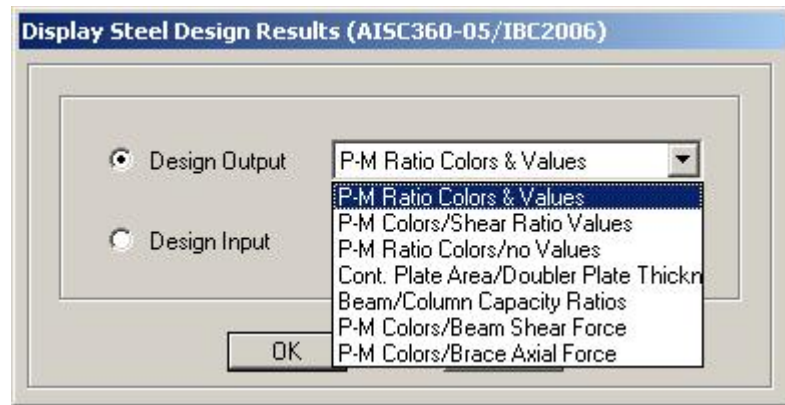


Figure 5-2 Choice of design output data for display on the model in the active window

Use the **Design menu > Steel Frame Design > Display Design Info** command in SAP2000/ETABS and the **Advanced > Frame Design > Steel > Display Design Information** command in CSiBridge to plot design input and output values directly on the model. The Display Steel Design Results form shown in Figures 5-1 and 5-2 will display. Choose the Design Output or Design Input option. One item can be selected from the drop-down list. For example, the P-M interaction ratios can be displayed by choosing the Design Output option and selecting P-M Ratio Colors & Values from the drop-down list. Click the **OK** button to display the longitudinal reinforcing in the active window.

The graphics can be displayed in 3D or 2D mode. The standard view transformations are available for all steel design information displays. Several buttons on the toolbar can be used to switch between 3D and 2D views. Alternatively, click the **View menu** and the **Set 3D View** or **Set 2D View** commands.

The onscreen graphical display can be sent to printer using any of the following commands. Use the **File menu > Print Graphics** command in SAP2000/ETABS and the **Orb > Print > Print Graphics** command in CSiBridge to print the active window. To capture the graphical display in a file for printing through another application, use the **File menu > Capture Enhanced Metafile** command in SAP2000/ETABS and the **Orb > Pictures > Metafile** command in CSiBridge to create an .emf file, or use the **File menu > Capture Picture** command in SAP2000/ETAB and the **Orb > Pictures** commands in CSiBridge to create a bitmap (.bmp) file. Create a screen capture of the active window using the **Alt+ Print Screen** keyboard keys in SAP2000/ETABS

or create a screen capture of the entire window using the **Ctrl + Print Screen** keyboard keys. Then use the **Ctrl+V** keyboard keys to paste the saved image into Paint or other graphical program.

By default the graphical displays are in color. It may be advantageous to view or present the display in gray-scale graphics or using a white background. Use the **Options menu > Color** command in SAP2000/ETABS and the **Orb > Settings > Colors** command in CSiBridge to set these options.

5.2 Tabular Display of Design Information

In addition to model definition and analysis results, the design information for all steel frame members or for only selected members can be displayed in tabular spreadsheet format. Currently, the program generates design summary data, PMM design details and shear design details. The tabular spreadsheet output can be displayed by selecting the **Display menu > Show Tables** command in SAP2000/ETABS and **Home > Display > Show Tables** command in CSiBridge to access the **Choose Tables for Display** form, an example of which is shown in Figure 5-3. That form can be used to choose which tables or sets of tables are to be displayed.

The names of the tables are displayed in a tree structure, which can be collapsed or expanded by clicking on an item in the tree. Click on the small check boxes preceding the items to select those tables for display. If a branch of the tree is selected, all of the tables under that branch are selected. The selected set of tables can be saved as a Named Set using the **Save Named Set** button. This named set can be used in the future for quick selection. If one or more frame members are selected on the structural model before accessing the Choose Tables for Display form, the Selection Only check box will be checked when the form displays and, the program will display information for the selected members only; uncheck the check box to display information for all applicable "unselected" members in the model. If the Show Unformatted check box is checked, the numbers will be displayed unformatted, instead of being displayed using a limited number of decimal digits. The unformatted option provides higher precision output that can then be copied into other programs.

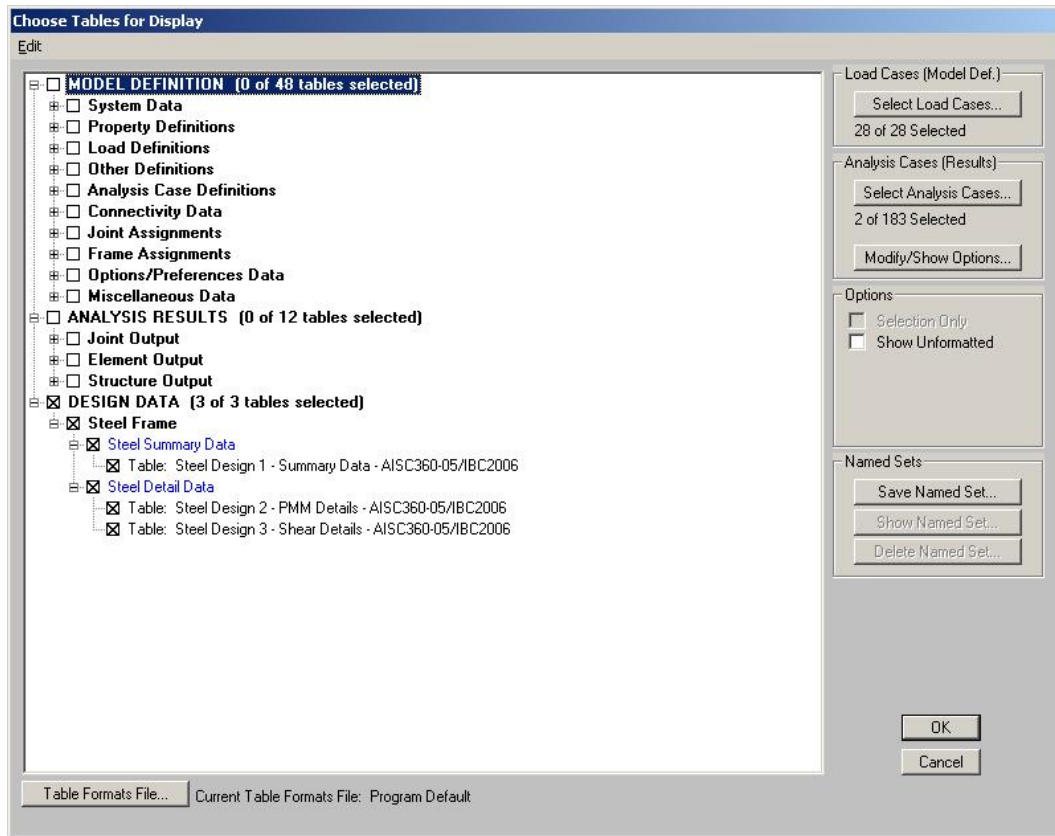


Figure 5-3 Choice of design data tables for tabular display

Use the other buttons in the form to tailor the data display. For example, click the **Select Load Patterns** button to specify which load patterns are to be included in the display of model definition data; click the **Select Load Case** and **Modify/Show Options** to specify which load cases are to be included and how analysis results are displayed.

After selecting all of the tables for steel frame design and the display options, click the **OK** button to display a form showing one of the selected design tables, with a drop-down list in the upper right-hand corner of the form that can be used to select other tables for display. A typical design table is shown in Figure 5-4.

| Frame Text | DesignSect Text | DesignType Text | Status Text | Ratio Unitless | RatioType Text | Combo Text |
|------------|-----------------|-----------------|-------------|----------------|----------------|------------|
| 1 | W14x90 | Column | No Messages | 0.769375 | PMM | DSTL5 |
| 2 | W14x90 | Column | No Messages | 0.912779 | PMM | DSTL5 |
| 3 | W14x90 | Column | No Messages | 0.914659 | PMM | DSTL5 |
| 4 | W14x90 | Column | No Messages | 0.461798 | PMM | DSTL5 |
| 5 | W14x90 | Column | No Messages | 0.769375 | PMM | DSTL5 |
| 6 | W14x90 | Column | No Messages | 0.912779 | PMM | DSTL5 |
| 7 | W24x55 | Beam | No Messages | 0.876453 | PMM | DSTL5 |
| 8 | W24x55 | Beam | No Messages | 0.934805 | PMM | DSTL5 |
| 9 | W24x55 | Beam | No Messages | 0.876453 | PMM | DSTL5 |
| 10 | W24x55 | Beam | No Messages | 0.934805 | PMM | DSTL5 |

Figure 5-4 A typical tabular display of design data

Use the scroll bars on the bottom and right side of the tables to scroll right and left or up and down if portions of the data table can not be displayed in the form's display area. The columns can be resized by clicking the left mouse button on the separator of the headers, holding down the left mouse button and then dragging the mouse to the left or right. Reset the column widths to their default values by selecting the **Format-Filter-Sort menu > Reset Default Column Widths** command on the form. The table can be split into two or more tables by clicking on the small black rectangular area near the bottom-left corner of the table, holding down the left mouse button, and then dragging the mouse button to the left or right. Repeat this process to add more splits. Use the split and horizontal scroll bar to put two columns side by side for easier comparison. The splits can be removed by selecting the **Format-Filter-Sort menu > Remove Splits** command on the form. Alternatively, remove the split by clicking, holding and dragging the left mouse button to merge the split key to its original location.

Select multiple consecutive columns by putting the cursor on the header, holding down the mouse button, and then dragging the mouse button left or right. Alternatively, depress the Shift key and click the left mouse button to select a range of columns.

Each of the individual fields (columns) can be formatted. Fields with text information can be set for specific types of alignment (center, left, right) and to specific widths. In addition to setting the alignment and column widths, fields with numeric data can be set for the maximum number of characters, zero tolerance, number of decimal digits and so forth. The tables can be formatted, filtered and sorted using multiple criteria accessed using the **Format-Filter-Sort** menu on the form. Filtering and sorting features can be useful in identifying critical cases. After specifying the table formatting information, save it to a format file that can be used in the future by selecting the appropriate feature available under the **Format-Filter-Sort** menu.

The current table (i.e., the table in the active window) can be exported to Excel, Access, .rtf., .html, and plain text formats. In both Excel spreadsheet and Access database formats, the tables can have many columns, making the tables very wide. In .rtf and .html formats, the tables are split at convenient points to make a reasonably printable document. In plain text format, the tables can be saved with or without the splits. To export a table to Excel, for example, select the **File menu > Export Current Table > To Excel** command. The program will export the entire table to an Excel spreadsheet workbook and will automatically open the file in MS Excel. Similarly, if the table is exported to other formats, the default editor specific to that format will open the document, provided that the editor is available in the computer. The table will be saved in that format only if the relevant editor is not available. Instead of exporting or displaying the currently displayed table, the entire set of available tables can be exported and displayed in the afore-mentioned formats by selecting the File menu and the appropriate submenu command. With these exporting and display features, the tables can be saved in many required formats and can be printed. Many other features of the design tables are left for the user to discover by using the program.

5.3 Detailed Display of Member Specific Information

The program has the capability to display the design details for a specific member. The information includes member identification, shape name, section properties, design combination name, design combination forces, and other design input data to check the design results. The information also includes stress ratios for P-M-M and other interactions, demand/capacity ratios from shear,

nominal strengths, design factors such as K , C_m , C_b , B_1 , B_2 , and so forth. The design details are displayed in a summary form and also are displayed for a specific load combination and for a specific station of a frame member.

When the design results are displayed on the model in the active window, the detailed design information can be accessed by **right clicking** on the desired frame member to display the Steel Stress Check Information form. Alternatively, click the **Design menu > Steel Frame Design > Interactive Steel Frame Design** command and then right click on the frame member. An example of that form is shown in Figure 5-5.

Steel Stress Check Information (AISC360-05/IBC2006)

Frame ID: 31 Analysis Section: W18X35
 Design Code: AISC360-05/IBC2006 Design Section: W18X35

| COMBO ID | STATION LOC | ----MOMENT INTERACTION CHECK----- | MAJ-SHR | MIN-SHR |
|----------|-------------|-----------------------------------|---------|---------|
| | | RATIO = AXL + B-MAJ + B-MIN | RATIO | RATIO |
| DSTL154 | 96.00 | 0.008 (T) = 0.000 + 0.008 + 0.000 | 0.000 | 0.000 |
| DSTL154 | 120.00 | 0.008 (T) = 0.000 + 0.007 + 0.000 | 0.000 | 0.000 |
| DSTL154 | 144.00 | 0.006 (T) = 0.000 + 0.006 + 0.000 | 0.001 | 0.000 |
| DSTL154 | 168.00 | 0.003 (T) = 0.000 + 0.002 + 0.000 | 0.002 | 0.000 |
| DSTL154 | 192.00 | 0.003 (T) = 0.000 + 0.002 + 0.001 | 0.002 | 0.000 |
| DSTL154 | 216.00 | 0.009 (T) = 0.000 + 0.007 + 0.001 | 0.003 | 0.000 |
| DSTL154 | 240.00 | 0.015 (T) = 0.000 + 0.014 + 0.002 | 0.003 | 0.000 |
| DSTL155 | 0.00 | 0.057 (T) = 0.000 + 0.051 + 0.006 | 0.001 | 0.000 |

Modify/Show Overwrites: Display Details for Selected Item: Display Complete Details:

Stylesheet: Default

Figure 5-5 A typical member specific steel stress check information summary

The Steel Stress Check Information form identifies the frame members and the analysis and design section, and includes a display area of mostly demand/capacity ratio data and a set of buttons that access forms that provide further details about the selected frame member. The display area reports the load combinations, the stress check stations, the P-M-M interaction ratio along with its axial and flexural components, and the shear stress ratios. The load combination is reported by its name, while the station is reported by its location,

which is measured from the I-end of the column. The number of reported line items in the text box is equal to the number of design combinations multiplied by the number of stations. Only one line item is highlighted in blue when the form first displays. That item highlights the largest demand/capacity ratio from P-M-M, major and minor shear or any other considered interaction ratio, unless a line item(s) has design overstress or an error. In that case, the item with the overstress or error will be selected and highlighted. If many line items are overstressed or have an error, the last among all such line items will be selected and highlighted.

The stress check information is always reported for the design section. If the member is assigned an individual section, the analysis and design section are always the same. If the member is assigned an Auto Select Section (a list of sections), the analysis and design section can be different, unless the design has converged.

The **Overwrites** and **Details** buttons near the bottom of the Steel Stress Check Information form can be used to access the Steel Frame Design Overwrites form, and the Steel Stress Check Data form, which displays detailed information about the selected frame element. While the latter form displays information in a non-editable format, the Overwrites form display the overwrite data in editable format. This allows the user to enter an interactive mode of design.

- **Overwrites** button. Click this button to access the Steel Frame Design Overwrites form. Use that form to make revisions to the steel frame design overwrites and then immediately review the new design results as a summary using the Steel Stress Check Information form, or in detail by clicking the **Details** button to access the Steel Stress Check Data form. Clicking the **OK** button on the Steel Frame Design Overwrites form temporarily saves any changes. To make the changes permanent, click the **OK** button on the Steel Stress Check Information form. To disregard the changes, click the **Cancel** button on the Steel Stress Check Information form. An example of an Overwrites form is shown in Figure 5-6.

Steel Frame Design Overwrites for AISC 360-05/IBC 2006

| Item | Value | |
|------|------------------------------------|--------------------|
| 1 | Current Design Section | Program Determined |
| 2 | Framing Type | Program Determined |
| 3 | Omega0 | Program Determined |
| 4 | Consider Deflection? | No |
| 5 | Deflection Check Type | Program Determined |
| 6 | DL Limit, L / | Program Determined |
| 7 | Super DL+LL Limit, L / | Program Determined |
| 8 | Live Load Limit, L / | Program Determined |
| 9 | Total Limit, L / | Program Determined |
| 10 | Total-Camber Limit, L / | Program Determined |
| 11 | DL Limit, abs | Program Determined |
| 12 | Super DL+LL Limit, abs | Program Determined |
| 13 | Live Load Limit, abs | Program Determined |
| 14 | Total Limit, abs | Program Determined |
| 15 | Total-Camber Limit, abs | Program Determined |
| 16 | Specified Camber | Program Determined |
| 17 | Net Area to Total Area Ratio | Program Determined |
| 18 | Live Load Reduction Factor | Program Determined |
| 19 | Unbraced Length Ratio (Major) | Program Determined |
| 20 | Unbraced Length Ratio (Minor) | Program Determined |
| 21 | Unbraced Length Ratio (LTB) | Program Determined |
| 22 | Effective Length Factor (K1 Major) | Program Determined |
| 23 | Effective Length Factor (K1 Minor) | Program Determined |
| 24 | Effective Length Factor (K2 Major) | Program Determined |

Item Description

Explanation of Color Coding for Values

Blue: All selected items are program determined

Black: Some selected items are user defined

Red: Value that has changed during the current session

Set To Prog Determined (Default) Values: All Items Selected Items

Reset To Previous Values: All Items Selected Items

OK Cancel

Figure 5-6 A typical member specific Steel Frame Design Overwrites form

- **Details** button. Click this button to access the Steel Stress Check Data form. Use the form to review all of the design details for the highlighted item. An example of a Steel Stress Check Data form is shown in Figure 5-7. The information includes the member ID, load combo and station identifications, steel design sections, section properties, design combination forces, stress ratios for P-M-M and other interactions, stress ratios for shear, nominal strengths, and design factors such as C_m , C_b , B_1 , B_2 , and so forth. Values that are not applicable are reported as N/A. Similarly, N/C and N/N indicate an item is “Not Calculated” and “Not Needed.”

Steel Frame Design AISC 360-05/IBC 2006

Steel Stress Check Data AISC 360-05/IBC 2006

File

AISC 360-05/IBC 2006 STEEL SECTION CHECK
 Combo : DSTL1
 Units : Kip, in, F

Units | Kip, in, F

Frame : 28 Design Sect: W18X35
 X Mid : -180.000 Design Type: Beam
 Y Mid : 240.000 Frame Type : Special Moment Frame
 Z Mid : 200.000 Sect Class : Compact
 Length : 360.000 Major Axis : 0.000 degrees counterclockwise from local 3
 Loc : 360.000 RLLF : 1.000

Area : 10.300 SMajor : 57.627 rMajor : 7.037 AUMajor: 5.310
 IMajor : 510.000 SMinor : 5.100 rMinor : 1.219 AUMinor: 4.250
 IMinor : 15.300 ZMajor : 66.500 E : 29000.000
 Ixy : 0.000 ZMinor : 8.060 Fy : 50.000

DESIGN MESSAGES
 kL/r > 200 (AISC B7)

STRESS CHECK FORCES & MOMENTS

| Location | Pu | Mu33 | Mu22 | Uu2 | Uu3 | Tu |
|----------|--------|---------|-------|-------|-------|-------|
| 360.000 | -0.399 | -49.482 | 0.000 | 0.783 | 0.000 | 0.000 |

PHI DEMAND/CAPACITY RATIO

| Governing Equation (H1-1b) | Total Ratio | P Ratio | MMajor Ratio | MMinor Ratio | Ratio Limit | Status Check |
|----------------------------|-------------|---------|--------------|--------------|-------------|--------------|
| | 0.054 | = 0.007 | + 0.046 | + 0.000 | 0.950 | OK |

AXIAL FORCE DESIGN

| | Pu Force | phi*Pnc Capacity | phi*Pnt Capacity |
|-------|----------|------------------|------------------|
| Axial | -0.399 | 26.670 | 463.500 |

MOMENT DESIGN

| | Mu Moment | phi*Mn Capacity | Cn Factor | B1 Factor | B2 Factor | K Factor | L Factor | Cb Factor |
|--------------|-----------|-----------------|-----------|-----------|-----------|----------|----------|-----------|
| Major Moment | -49.465 | 1065.592 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 2.254 |
| Minor Moment | 0.000 | 362.700 | 1.000 | 0.988 | 1.000 | 1.000 | 1.000 | |

SHEAR DESIGN

| | Uu Force | phi*Un Capacity | Stress Ratio | Status Check | Tu Torsion |
|-------------|----------|-----------------|--------------|--------------|------------|
| Major Shear | 0.783 | 159.300 | 0.005 | OK | 0.000 |
| Minor Shear | 0.000 | 137.700 | 0.000 | OK | 0.000 |

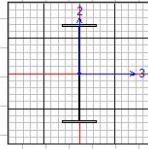


Figure 5-7 A typical Steel Stress Check Data form

Before clicking the button, highlight an item for the desired design station and design load combination in the Steel Stress Check Information display area by clicking on the line. The data subsequently displayed will relate to the highlighted item. By default, the most critical line item is selected when the form first displays, as described previously.

To increase or decrease the width of the Steel Stress Check Data form, put the cursor near the right edge of the form, click the left mouse button, and drag the mouse cursor towards the left or right. Similarly, the height of the form can be increased or decreased.

The text in the form can be dragged in any direction by positioning the cursor in the middle of the form, and then clicking the left mouse button

and dragging the text in the desired direction. Similarly, the graphical display of the column section can also be dragged in any direction.

Use the Units drop-down list in the upper right-hand corner of the form to change the units used to display the data. Data displayed on the form can be sent directly to the printer by selecting the **File menu > Print** command on the form. The program allows limited page setup options using the **Print Setup Command** on the **File** menu on the form.

The Steel Stress Check Information form also includes a **Tabular Data** button that when clicked displays member specific design details in a spreadsheet type format. The tabular display of design information has been described in the previous section. In that case, the information displayed is specific to the selected member only. The tabular output is shown for all stations and all design load combinations for the selected member. An example of design details table that displays after clicking the **Tabular Data** button is shown in Figure 5-8.

The screenshot shows a software window titled "Steel Details 1 - Summary Data - AISC360-05/IBC2006". The window contains a menu bar (File, View, Format, Filter, Sort, Select, Options) and a status bar (Units: As Noted). The main area displays a table with the following columns: Frame Text, DesignSect Text, DesignType Text, Status Text, Ratio Unitless, RatioType Text, Combo Text, Location in, ErrMsg Text, and WarnMsg Text. The table lists design details for member 31 across various design sections (W18x35) and design types (Beam). The status for all entries is "No Messages". The ratio values range from 0.00242 to 0.00725. The ratio types include Major Shear and PMM. The combo types include DSTL1 and DSTL5. The location values range from 0 to 216. The error and warning message columns are empty for all entries.

| Frame Text | DesignSect Text | DesignType Text | Status Text | Ratio Unitless | RatioType Text | Combo Text | Location in | ErrMsg Text | WarnMsg Text |
|------------|-----------------|-----------------|-------------|----------------|----------------|------------|-------------|-------------|--------------|
| 31 | W18x35 | Beam | No Messages | 0.00242 | Major Shear | DSTL1 | 0 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.003492 | PMM | DSTL1 | 24 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.006871 | PMM | DSTL1 | 48 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.008959 | PMM | DSTL1 | 72 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.009456 | PMM | DSTL1 | 96 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.008662 | PMM | DSTL1 | 120 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.006477 | PMM | DSTL1 | 144 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.0029 | PMM | DSTL1 | 168 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.00258 | Major Shear | DSTL1 | 192 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.008459 | PMM | DSTL1 | 216 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.016208 | PMM | DSTL1 | 240 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.002075 | Major Shear | DSTL5 | 0 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.002993 | PMM | DSTL5 | 24 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.00689 | PMM | DSTL5 | 48 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.007594 | PMM | DSTL5 | 72 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.008185 | PMM | DSTL5 | 96 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.007424 | PMM | DSTL5 | 120 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.005951 | PMM | DSTL5 | 144 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.002486 | PMM | DSTL5 | 168 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.00215 | Major Shear | DSTL5 | 192 | No Messages | No Messages |
| 31 | W18x35 | Beam | No Messages | 0.00725 | PMM | DSTL5 | 216 | No Messages | No Messages |

Figure 5-8 Member specific design details in tabular format

5.4 Output of Design Information

In addition to model definition and analysis results, the design information for all steel frame members or for selected frames only can be saved in tabular format. Currently for AISC 360-05/IBC 2006 code, the program saves design summary data, PMM design details, and shear design details. Save the file output by selecting the **File menu > Print Tables** command in SAP2000/ETAB

and the **Orb > File > Print > Print Tables** command in CSiBridge to access the Choose Tables for Printing form. An example of that form is shown in Figure 5-9. Use the options on the form to choose which table or set of tables to save in a file or print. This form is very similar to the Choose Tables for Display form, which has been described earlier in this chapter in the "Tabular Display of Design Information" section.

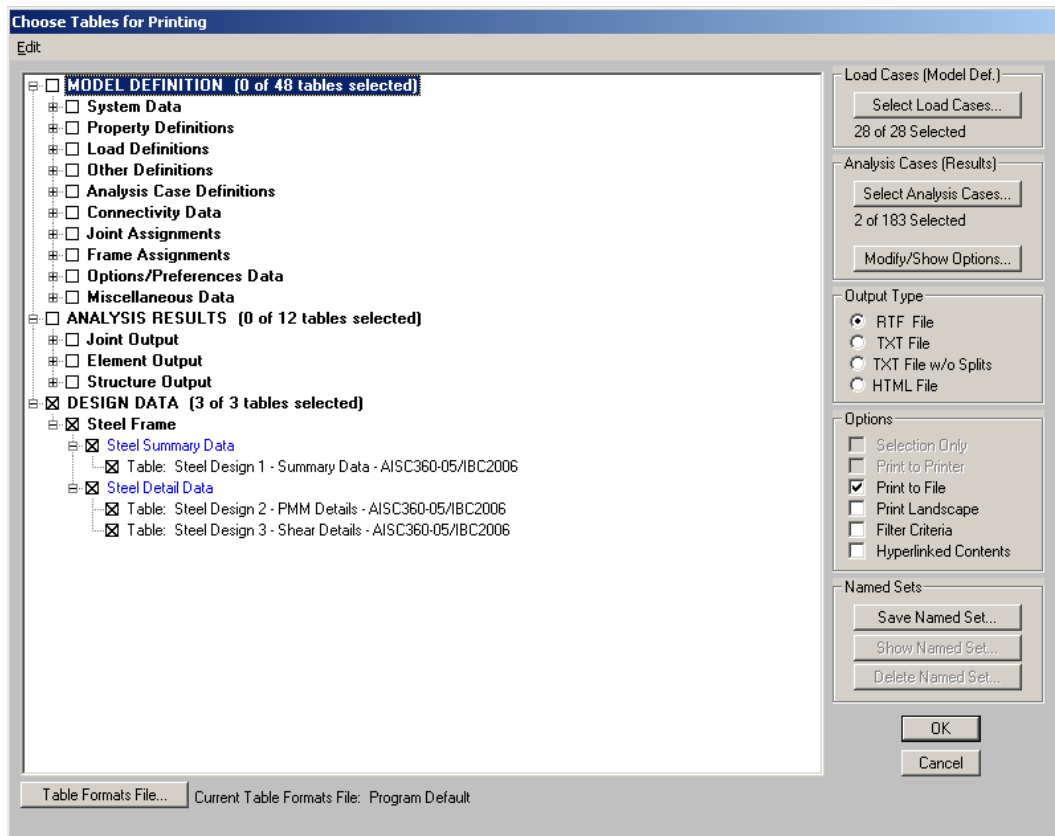


Figure 5-9 Choice of design tables for saving in a file or printing

The name of the tables are displayed in a tree structure, which can be collapsed or expanded by clicking on an item in the tree. Click on the small check boxes preceding the items to select those tables for printing or saving to a file. If a branch of the tree is selected, all of the tables under that branch are selected. When all options for printing or saving the data to file have been specified, the settings can be saved as a Named Set using the **Save Named Set** button. The Named Set can be easily recalled in the future, reducing the need to reselect the options and ensuring that output is consistent from one printing effort to another.

If one or more structural members are selected before the Choose Tables for Printing form is accessed, the Selection Only check box will be checked, and the program will save or print the data for the selected members only; uncheck the check box to save or print the data for all appropriate "unselected" members.

The output can be generated in a variety of formats, including rich text format (.rft), plain text with and without splits or page breaks (.txt), and hyperlink text markup language (.htm) by choosing the appropriate option on the right side of the form.

Printed output can be specified to have a landscaped orientation, in which the width of the resulting printout on a given page is longer than the height of the printout.

Filtering criteria can be applied if those criteria were specified using the **Format-Filter-Sort menu > Format Table** command when the selected data tables were displayed using the **Display menu > Show Tables** command in SAP2000/ETABS and the **Home > Display > Show Tables** command in CSiBridge. The output also can be specified to include a hyperlinked contents to facilitate accessing specific areas of the printout.

There are other buttons on the form that do not affect saving or printing design information. For example, the **Select Load Patterns** button affects only saving/printing model definition data. The **Select Load Cases** and **Modify/Show Options** buttons affect only saving/printing analysis results.

After clicking all the necessary tables for steel frame design and all necessary options, clicking the **OK** button will save/print the design tables.

Although the **File name > Print Tables** command and the **Orb > File > Print > Print Tables** command paths are dedicated for saving/printing design information, these are not the only paths to do so. Design tables can be saved in different formats using the **Display menu > Show Tables** command in SAP2000/ETABS and the **Home > Display > Show Tables** command in CSiBridge.

5.5 Error Messages and Warnings

Error messages and warnings may be displayed in the steel frame design output. The messages are numbered. A list of error messages and warnings used in Steel Frame Design for all the design codes is provide in Appendix F. However, all of the messages are not applicable to the AISC 360-05/IBC 2006 Code.

Appendix A P-Delta Effects

Modern design provisions are based on the principle that the member forces are calculated by a second-order elastic analysis, where the equilibrium is satisfied on the deformed geometry of the structure. The effects of the loads acting on the deformed geometry of the structure are known as the second-order or the P-Delta effects.

The P-Delta effects come from two sources: global lateral translation of the frame and the local deformation of members within the frame.

Consider the frame object shown in Figure A-1, which is extracted from a story level of a larger structure. The overall global translation of this frame object is indicated by Δ . The local deformation of the member is shown as δ . The total second order P-Delta effects on this frame object are those caused by both Δ and δ .

The program has an option to consider P-Delta effects in the analysis. When you consider P-Delta effects in the analysis, the program does a good job of capturing the effect due to the Δ deformation ($P-\Delta$ effect) shown in Figure B-1, but it does not typically capture the effect of the δ deformation ($P-\delta$ effect), unless, in the model, the frame object is broken into multiple elements over its length.

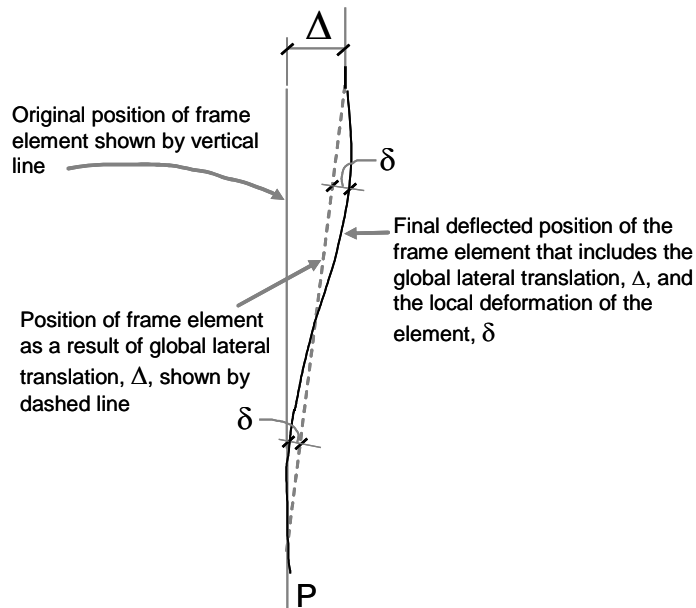


Figure A-1 *P-Δ and P-δ effects*

In design codes, required strengths are usually required to be determined using a second-order analysis that considers both *P-Δ* and *P-δ* effects. Approximate second-order analysis procedures based on amplification of responses from first-order analysis for calculating the required flexural and axial strengths are common in current design codes and have the following general form:

$$M_{CAP} = B_1 M_{nt} + B_2 M_{lt} \quad (\text{AISC C2-1a})$$

$$P_{CAP} = P_{nt} + B_2 P_{lt} \quad (\text{AISC C2-1b})$$

where,

M_{CAP}, P_{CAP} = Required axial and flexural design capacities

M_{nt}, P_{nt} = Required axial and flexural capacities from first-order analysis of the member assuming there is no translation of the frame (i.e., associated with the δ deformation in Figure 2-1)

M_{lt}, P_{lt} = Required axial and flexural capacities from first-order analysis of the member as a result of lateral translation of the frame

only (i.e., associated with the Δ deformation in Figure A-1)

B_1 = Unitless amplification factor multiplying M_m

B_2 = Unitless amplification factor multiplying M_{lt}, P_{lt}

Depending on the choice of analysis methods, which is provided by the ANSI/AISC 360-05 code, a rigorous second order analysis or the amplification of first order analysis results to estimate the effect of second order effects is required. The program has the capability of performing both. In the first case, the required strengths are determined directly from the analysis results without any amplification factors (i.e., B_1 and B_2 are equal to 1). However, these amplification factors can always be overwritten by the user on a member-by-member basis, if desired, using the overwrite option.

To properly capture the P- δ effect in a finite element analysis, each element, especially column elements, must be broken into multiple finite elements. Although a single element per member can capture the P- δ effect to some extent, the program considers that inadequate. For practical reasons, the software internally divides the column elements into two members. The user must provide additional subdivisions where a column is expected to have multiple inflection points.

In general, steel frame design requires consideration of P-Delta effects in the analysis before the check/design is performed. Although two elements per line object are generally adequate to capture the P- Δ effect, it is recommended to use more than two elements per line object for the cases where both P- Δ and P- δ effects are to be considered for a member having multiple points of inflection. However, explicit manual breaking of the member into elements has other consequences related to member end moments and unbraced segment end moment. It is recommended that the members be broken internally by the program. In this way, the member is recognized as one unit, end of the members are identified properly, and P- Δ and P- δ effects are captured better.

Appendix B

Steel Frame Design Preferences

The Steel Frame Design Preferences are basic assignments that apply to all of the steel frame members. Tables B-1, B-2, and B-3 list Steel Frame Design Preferences for "AISC 360-05/IBC 2006." Default values are provided for all preference items. Thus, it is not necessary to specify or change any of the preferences. However, at least review the default values to ensure they are acceptable. Some of the preference items also are available as member specific overwrite items. The Overwrites are described in Appendix C. Overwritten values take precedence over the preferences.

Table B-1: Steel Frame Design Preferences

| Item | Possible Values | Default Value | Description |
|---------------------|---|-------------------------|--|
| Design Code | Design codes available in the current version | AISC360-05/ IBC 2006 | The selected design code. Subsequent design is based on this selected code. |
| Time History Design | Envelopes, Step-by-Step | Envelopes | Toggle for design combinations that include a time history designed for the envelope of the time history, or designed step-by-step for the entire time history. If a single design combination has more than one time history case in it, that design combination is designed for the envelopes of the time histories, regardless of what is specified here. |

Table B-1: Steel Frame Design Preferences

| Item | Possible Values | Default Value | Description |
|-------------------------------|---------------------------------------|---|---|
| Framing Type | SMF, IMF, OMF, SCBF, OCBF, OCBFI, EBF | SMF | This item is used for ductility considerations in the design, when seismic provisions are considered. |
| Seismic Design Category | A, B, C, D, E, F | D | This item varies with the Seismic Hazard Exposure Group and the Effective Peak Velocity Related Acceleration. |
| Design Provision | ASD, LRFD | LRFD | Application provisions for calculation of allowable/design and required strength of individual elements. Selection of ASD will enable additional fields for safety factor overwrites, whereas selection of LRFD will enable additional fields for resistance factors. |
| Analysis Method | 7 Values | Direct Analysis Method with General 2 nd Order Analysis and τ_b Fixed | Indicates the method used to check/design the steel members. The design module does not verify the acceptability of the selected design analysis method; the user is expected to verify acceptability. Also, the user is expected to set the appropriate stiffness modification factors and to supply the combinations with appropriate notional loads. |
| Notional Load Coefficient | > 0 | 0.002 | The coefficient used to define the notional load as a fraction of a given gravity load pattern. |
| Ignore Seismic Code? | Yes, No | No | Toggle to consider (No) or not consider (Yes) the seismic part of the code in design. |
| Ignore Special Seismic Load? | Yes, No | No | Toggle to consider (No) or not consider (Yes) special seismic load combinations in design. |
| Is Doubler Plate Plug Welded? | Yes, No | Yes | Toggle to indicate if the doubler-plate is plug welded (Yes) or it is not plug welded (No). |
| HSS Welding Type | ERW, SAW | ERW | Indicates the procedure used for welding the steel members. |
| Reduce HSS Thickness? | Yes, No | Yes | Toggle to consider if the HS (Box or Pipe) thickness is reduced (Yes) or should not be reduced (No). |
| Consider Deflection? | Yes, No | No | Toggle to consider the deflection limit (Yes) or to not consider the deflection limit (No). |
| DL Limit, L/ | ≥ 0 | 120 | Deflection limit for dead load. Inputting 120 means that the limit is L/120. Inputting zero means no check will be made of this item. |

Appendix B Steel Frame Design Preferences

Table B-1: Steel Frame Design Preferences

| Item | Possible Values | Default Value | Description |
|----------------------------------|-----------------|---------------|---|
| Super DL+LL Limit, L/ | ≥ 0 | 120 | Deflection limit for superimposed dead plus live load. Inputting 120 means that the limit is L/120. Inputting zero means no check will be made of this item. |
| Live Load Limit, L/ | ≥ 0 | 360 | Deflection limit for superimposed live load. Inputting 360 means that the limit is L/360. Inputting zero means no check will be made of this item. |
| Total Limit, L/ | ≥ 0 | 240 | Deflection limit for total load. Inputting 240 means that the limit is L/240. Inputting zero means no check will be made of this item. |
| Total-Camber Limit, L/ | ≥ 0 | 240 | Limit for net deflection. Camber is subtracted from the total load deflection to get net deflection. Inputting 240 means that the limit is L/240. Inputting zero means no check will be made of this item. |
| Pattern Live Load Factor | ≤ 1.0 | 0.75 | The live load factor for automatic generation of load combinations involving pattern live loads and dead loads. |
| D/C Ratio Limit | ≤ 1.0 | 0.95 | The demand/capacity ratio limit to be used for acceptability. D/C ratios that are less than or equal to this value are considered acceptable. The program will select members from the auto select list with D/C ratios less than or equal to this value. |
| Maximum Number of Auto Iteration | ≥ 1 | 1 | Sets the number of iterations of the analysis-design cycle that the program will complete automatically assuming that the frame members have been assigned auto select sections. This is currently only available in ETABS. |

Table B-2 Additional Steel Frame Design Preferences LRFD Provision

| Item | Possible Values | Default Value | Description |
|---|-----------------|---------------|--|
| Phi (Bending) | ≤ 1.0 | 0.9 | Resistance factor for flexure. |
| Phi (Compression) | ≤ 1.0 | 0.9 | Resistance factor for compression. |
| Phi (Tension-Yielding) | ≤ 1.0 | 0.9 | Resistance factor for yielding in tension. |
| Phi (Tension-Fracture) | ≤ 1.0 | 0.75 | Resistance factor for tension rupture. |
| Phi (Shear) | ≤ 1.0 | 0.9 | Resistance factor for shear. |
| Phi (Shear, Short Webbed Rolled I-Shapes) | ≤ 1.0 | 1.0 | Resistance factor for shear for specific short-webbed rolled I-Shapes. |
| Phi (Torsion) | ≤ 1.0 | 0.9 | Resistance factor for torsion. |

Table B-3 Additional Steel Frame Design Preferences for ASD Provision

| Item | Possible Values | Default Value | Description |
|--|------------------------|----------------------|--|
| Omega (Bending) | ≥ 1.0 | 1.67 | Safety factor for flexure. |
| Omega (Compression) | ≥ 1.0 | 1.67 | Safety factor for compression. |
| Omega (Tension-Yielding) | ≥ 1.0 | 1.67 | Safety factor for yielding in tension. |
| Omega (Tension-Fracture) | ≥ 1.0 | 2.00 | Safety factor for tension rupture. |
| Omega (Shear) | ≥ 1.0 | 1.67 | Safety factor for shear. |
| Omega (Shear, Short Webbed Rolled I-Shape) | ≥ 1.0 | 1.50 | Safety factor for shear for specific short-webbed rolled I-Shapes. |
| Omega (Torsion) | ≥ 1.0 | 1.67 | Safety factor torsion. |

Appendix C

Steel Frame Design Procedure Overwrites

The structural model may contain frame elements made of several structural materials: steel, concrete, aluminum, cold-formed steel and other materials. The program supports separate design procedures for each material type. By default the program determines the design procedure from the material of the frame member.

The software allows the user to turn off or turn on design of specific members by selecting *No Design* or *Default from material*. Refer to the program Help for information about overwriting the design procedure.

Overwrites

The steel frame design Overwrites are basic assignments that apply only to those elements to which they are assigned. Table C-1 lists Steel Frame Design Overwrites for "AISC 360-05/IBC 2006." Default values are provided for all overwrite items. Thus, it is not necessary to specify or change any of the overwrites. However, at least review the default values to ensure they are acceptable. When changes are made to overwrite items, the program applies the changes only to the elements to which they are specifically assigned. overwritten values take precedence over the preferences (Appendix B).

Table C-1 Steel Frame Design Overwrites for "AISC 360-05/IBC 2006"

| Item | Possible Values | Default Value | Description |
|------------------------|---------------------------------------|------------------|--|
| Current Design Section | Any defined steel section | Analysis section | The design section for the selected frame object. When this Overwrite is applied, any previous auto select section assigned to the frame object is removed. |
| Fame Type | SMF, IMF, OMF, SCBF, OCBF, OCBFI, EBF | From Preferences | This item is used for ductility considerations in the design. |
| Omega O | ≥ 1.0 | Calculated | This factor is related to seismic force and ductility. |
| Consider Deflection? | Yes, No | From Preferences | Toggle to consider the deflection limit (Yes) or to not consider the deflection limit (No) in design. |
| Deflection Check Type | Ratio, Absolute, Both | Both | Choose to consider deflection limit as an absolute, as a divisor of the beam length, as both, or with no deflection limit. |
| DL Limit, L/ | ≥ 0 | From Preferences | Deflection limit for dead load. Inputting 120 means that the limit is L/120. Inputting zero means no check will be made of this item. |
| Super DL+LL Limit, L/ | ≥ 0 | From Preferences | Deflection limit for superimposed dead plus live load. Inputting 120 means that the limit is L/120. Inputting zero means no check will be made of this item. |
| Live Load Limit, L/ | ≥ 0 | From Preferences | Deflection limit for superimposed live load. Inputting 360 means that the limit is L/360. Inputting zero means no check will be made of this item. |
| Total Limit, L/ | ≥ 0 | From Preferences | Deflection limit for total load. Inputting 240 means that the limit is L/240. Inputting zero means no check will be made of this item. |
| Total-Camber Limit, L/ | ≥ 0 | From Preferences | Limit for net deflection. Camber is subtracted from the total load deflection to get net deflection. Inputting 240 means that the limit is L/240. Inputting zero means no check will be made of this item. |
| DL Limit, abs | ≥ 0 | 1. | Deflection limit for dead load. Inputting zero means no check will be made of this item. |
| Super DL+LL Limit, abs | ≥ 0 | 1. | Deflection limit for superimposed dead plus live load. Inputting zero means no check will be made of this item. |
| Live Load Limit, abs | ≥ 0 | 1. | Deflection limit for superimposed live load. Inputting zero means no check will be made of this item. |
| Total Limit, abs | ≥ 0 | 1. | Deflection limit for total load. Inputting zero means no check will be made of this item. |

Appendix C Frame Design Overwrites

Table C-1 Steel Frame Design Overwrites for "AISC 360-05/IBC 2006"

| Item | Possible Values | Default Value | Description |
|------------------------------------|-----------------|---------------|---|
| Total-Camber Limit, abs | ≥ 0 | 1. | Deflection limit for net deflection. Camber is subtracted from the total load deflection to get net deflection. Inputting a value of 240 means that the limit is $L/240$. Inputting zero means no check will be made of this item. |
| Specified Camber | ≥ 0 | 0 | The specified amount of camber to be reported in the design output and to be used in the net deflection check. |
| Live Load Reduction Factor | ≥ 0 | Calculated | The reducible live load is multiplied by this factor to obtain the reduced live load for the frame object. Specifying zero means the value is program determined. |
| Net Area to Total Area Ratio | ≥ 0 | 1.0 | The ratio of the net area at the end joint to gross cross-sectional area of the section. This ratio affects the design of axial tension members. Specifying zero means the value is the program default, which is 1. |
| Unbraced Length Ratio (Major) | ≥ 0 | Calculated | Unbraced length factor for buckling about the frame object major axis; specified as a fraction of the frame object length. This factor times the frame object length gives the unbraced length for the object. Specifying zero means the value is program determined. |
| Unbraced Length Ratio (Minor) | ≥ 0 | Calculated | Unbraced length factor for buckling about the frame object minor axis; specified as a fraction of the frame object length. This factor times the frame object length gives the unbraced length for the object. Specifying zero means the value is program determined. |
| Unbraced Length Ratio (LTB) | ≥ 0 | L22 | Unbraced length factor for lateral-torsional buckling for the frame object; specified as a fraction of the frame object length. This factor times the frame object length gives the unbraced length for the object. Specifying zero means the value is program determined. |
| Effective Length Factor (K1 Major) | ≥ 0 | 1.0 | Effective length factor for buckling about the frame object major axis; specified as a fraction of the frame object length. This factor times the frame object length gives the effective length for the object. Specifying zero means the value is program determined. For beam design, this factor is always taken as 1, regardless of any other value specified in the Overwrites. This factor is used for the B_1 factor. |

Table C-1 Steel Frame Design Overwrites for "AISC 360-05/IBC 2006"

| Item | Possible Values | Default Value | Description |
|------------------------------------|-----------------|---------------|--|
| Effective Length Factor (K1 Minor) | ≥ 0 | 1.0 | Effective length factor for buckling about the frame object minor axis; specified as a fraction of the frame object length. This factor times the frame object length gives the effective length for the object. Specifying zero means the value is program determined. For beam design, this factor is always taken as 1, regardless of any other value specified in the Overwrites. This factor is used for the B_1 factor. |
| Effective Length Factor (K2 Major) | ≥ 0 | Calculated | Effective length factor for buckling about the frame object major axis assuming that the frame is braced at the joints against sideway; specified as a fraction of the frame object length. This factor times the frame object length gives the effective length for the object. Specifying zero means the value is program determined. For beam design, this factor is always 1, regardless of any other values specified in the Overwrites. The factor is used for axial compression capacity. |
| Effective Length Factor (K2 Minor) | ≥ 0 | Calculated | Effective length factor for buckling about the frame object minor axis assuming that the frame is braced at the joints against sideway; specified as a fraction of the frame object length. This factor times the frame object length gives the effective length for the object. Specifying zero means the value is program determined. For beam design, this factor is always 1, regardless of any other values specified in the Overwrites. The factor is used for axial compression capacity. |
| Effective Length Factor (K LTB) | ≥ 0 | K2 minor | Effective length factor for lateral-torsional buckling; specified as a fraction of the frame object length. This factor times the frame object length gives the effective length for the object. Specifying zero means the value is program determined. For beam design, this factor is taken as 1 by default. The values should be set by the user. |
| Moment Coefficient (Cm Major) | ≥ 0 | Calculated | Unitless factor; Cm for major axis bending is used in determining the interaction ratio. Inputting zero means the value is program determined. |
| Moment Coefficient (Cm Minor) | ≥ 0 | Calculated | Unitless factor; Cm for minor axis bending is used in determining the interaction ratio. Inputting zero means the value is program determined. |
| Bending Coefficient (Cb) | ≥ 0 | Calculated | Unitless factor; Cb is used in determining the interaction ratio. Inputting zero means the value is program determined. |
| NonSway Moment Factor (B1 Major) | ≥ 0 | Calculated | Unitless moment magnification factor for non-sway major axis bending moment. Specifying zero means the value is program determined. |
| NonSway Moment Factor (B1 Minor) | ≥ 0 | Calculated | Unitless moment magnification factor for non-sway minor axis bending moment. Specifying zero means the value is program determined. |

Table C-1 Steel Frame Design Overwrites for "AISC 360-05/IBC 2006"

| Item | Possible Values | Default Value | Description |
|-------------------------------|-----------------|------------------|---|
| Sway Moment Factor (B2 Major) | ≥ 0 | 1.0 | Unitless moment magnification factor for sway major-axis bending moment. Specifying zero means the value is program determined. The program determined value is taken as 1 because it is assumed that P-Delta effects were specified to be included in the analysis, and thus no further magnification is required. |
| Sway Moment Factor (B2 Minor) | ≥ 0 | 1.0 | Unitless moment magnification factor for sway major-axis bending moment. Specifying zero means the value is program determined. The program determined value is taken as 1 because it is assumed that P-Delta effects were specified to be included in the analysis, and thus no further magnification is required. |
| HSS Welding Type | ERW, SAW | From Preferences | Indicates the procedure used to check/design the steel members. |
| Reduce HSS Thickness? | Yes, No | From Preferences | Toggle to consider if the HS (Box or Pipe) thickness is reduced (Yes) or should not be reduced (No). |
| Yield Stress, Fy | ≥ 0 | From Material | Material yield strength used in the design/check. Specifying zero means the value is program determined. The program determined value is taken from the material property assigned to the frame object. |
| Overstrength Factory, Ry | ≥ 0 | From Material | The ratio of the expected yield strength to the minimum specified yield strength. This ratio is used in capacity-based design for special seismic cases. Specifying zero means the value is program determined. |
| Compressive Capacity, Pnc | ≥ 0 | Calculated | Nominal axial compressive capacity. Specifying zero means the value is program determined. |
| Tensile Capacity, Pnt | ≥ 0 | Calculated | Nominal axial tensile capacity. Specifying zero means the value is program determined. |
| Major Bending Capacity, Mn3 | ≥ 0 | Calculated | Nominal bending moment capacity in major axis bending. Specifying zero means the value is program determined. |
| Minor Bending Capacity, Mn2 | ≥ 0 | Calculated | Nominal bending moment capacity in minor axis bending. Specifying zero means the value is program determined. |
| Major Shear Capacity, Vn2 | ≥ 0 | Calculated | Nominal shear capacity force for major direction shear. Specifying zero means the value is program determined. |
| Minor Shear Capacity, Vn3 | ≥ 0 | Calculated | Nominal shear capacity force for minor direction shear. Specifying zero means the value is program determined. |

Table C-1 Steel Frame Design Overwrites for "AISC 360-05/IBC 2006"

| Item | Possible Values | Default Value | Description |
|-----------------|-----------------|---------------|--|
| D/C Ratio Limit | ≥ 0 | Calculated | The demand/capacity ratio limit to be used for acceptability. D/C ratios that are less than or equal to this value are considered acceptable. Specifying zero means the value is program determined. |

Appendix D

Interactive Steel Frame Design

The Interactive Steel Frame Design command is a powerful mode that allows the user to review the design results for any steel frame design and interactively revise the design assumptions and immediately review the revised results.

Note that a design must have been run for the interactive design mode to be available. With the design results displayed, right click on a frame object to display the Steel Stress Check Information form for the member. Click on the **Overwrites** button to display the Design Overwrites form, where the member section or other design parameters may be changed. Clicking **OK** on this form results in an immediate updating of the results displayed on the Steel Stress Check Information form.

Appendix E

Analysis Sections vs. Design Sections

Analysis sections are those section properties used to analyze the model when an analysis is run (refer to the program Help for information about running an analysis). The design section is whatever section is used in the steel frame design. It is possible for the last used analysis section and the current design section to be different. For example, an analysis may be run using a W18X35 beam, and then in the design, it may be found that a W16X31 beam worked. In that case, the last used analysis section is the W18X35 and the current design section is the W16X31. Before the design process is complete, verify that the last used analysis section and the current design section are the same. Refer to the program Help for information about completing this task.

The program keeps track of the analysis section and the design section separately. Note the following about analysis and design sections:

- Assigning a frame section property assigns the section as both the analysis section and the design section.
- Running an analysis always sets the analysis section to be the same as the current design section.
- Assigning an Auto Select section list to a frame object initially sets the analysis and design section to be the section in the list with the median weight.

- Unlocking a model deletes the design results, but it does not delete or change the design section.
- Altering the Design Combinations in any way deletes the design results, but does not delete or change the design section.
- Altering any of the steel frame design preferences deletes the design results, but does not delete or change the design section.

Appendix F Error and Warning Messages

This appendix provides all the possible error message that can be offered by the Steel Frame Design model of the program. Some of these messages are relevant to the "AISC 360-05/IBC 2006" design code. Others are relevant to the other design codes supported by the program. However, the entire list is presented here for completeness.

| Error Number | Description |
|--------------|------------------------|
| 1 | $kl/r > 200$ |
| 2 | $l/r > 300$ |
| 3 | $P > P_e$ |
| 4 | $P > 0.85P_y$ |
| 5 | $P > 0.75P_y$ |
| 6 | $1/r > 720/\sqrt{F_y}$ |
| 7 | $1 > 96r_y$ |

| Error Number | Description |
|--------------|---|
| 8 | $h/t_w > 380/\sqrt{F_y}$ |
| 9 | Section is slender |
| 10 | Section is Class 4 |
| 11 | Section is not plastic |
| 12 | $P_u > P_e$ (B1 is undefined) |
| 13 | $C_f > C_e$ (U1 is undefined) |
| 14 | $b_f/2t_f > 52/\sqrt{F_y}$ |
| 15 | $1u > 76b_f/\sqrt{F_y}$ |
| 16 | $f_e > F_e$ |
| 17 | $l/r > 180$ |
| 18 | $l/r > 250$ |
| 19 | $1/r > 120$ |
| 20 | $l/r > 140$ |
| 21 | $P_u > \Phi * P_e$ (Delta b is undefined) |
| 22 | N/C (Not Calculated) |
| 23 | Internal Program Error |
| 24 | Section is too slender |
| 25 | $1/r > 1000/\sqrt{F_y}$ |
| 26 | Story drift too high |
| 27 | $b_f/2t_f > 52/\sqrt{F_y}$ |

| Error Number | Description |
|--------------|---------------------------------------|
| 28 | $b/t > 100/\text{Sqrt}(F_y)$ |
| 29 | $d/t > 1300/F_y$ |
| 30 | $b/t > 52/\text{sqrt}(F_y)$ |
| 31 | Section is not compact |
| 32 | $t_z < (d_z + w_z)/90$ |
| 33 | $b/t > 100/\text{Sqrt}(F_y)$ |
| 34 | $1/r > 2500/F_y$ |
| 35 | $F_y > 50 \text{ ksi}$ |
| 36 | Link is too long |
| 37 | Section is not seismically compact |
| 38 | Phi factor less than or equal to zero |
| 39 | $1/o/f > 150 * \text{Sqrt}(235/f_y)$ |
| 40 | $1/o/f > 300 * \text{Sqrt}(235/f_y)$ |
| 41 | $1/o/f > 200 * \text{Sqrt}(235/f_y)$ |
| 42 | $1/o/f > 150 * \text{Sqrt}(235/f_y)$ |
| 43 | $1/o/f > 120 * \text{Sqrt}(235/f_y)$ |
| 44 | $1/o/f > 100 * \text{Sqrt}(235/f_y)$ |
| 45 | $1/o/f > 90 * \text{Sqrt}(235/f_y)$ |
| 46 | $1/o/f > 80 * \text{Sqrt}(235/f_y)$ |
| 47 | $1/o/f > 60 * \text{Sqrt}(235/f_y)$ |

| Error Number | Description |
|--------------|--|
| 48 | $tz < (dz+wz)/70$ |
| 49 | $1/r > 60$ |
| 50 | $1/r > 0.086 \cdot r_y \cdot E / F_y$ |
| 51 | $kl/r > 4.23 \cdot \sqrt{e/E_y}$ |
| 52 | Link Rotation is too high |
| 53 | Phib factor less than or equal to zero |
| 54 | $\lambda_y > 120 \cdot \sqrt{235/f_y}$: Phib is no longer correct |
| 55 | $0.8 N/N_{ey} > .0$: Column is unstable |
| 56 | Beam/Column capacity ratio exceeds limit |
| 57 | Capacity ratio exceeds limit |
| 58 | Section is seismically slender & |
| 59 | $tz < (dz+wz)/90$ |
| 60 | Beam/column capacity ratio exceed limit |
| 61 | Section is slender |
| 62 | Section is unknown |
| 63 | Section is not supported for design |
| 64 | Section is too slender – Effective area negative |
| 65 | Section is too slender – Effective Moment of inertia negative |
| 66 | Section is too slender – D/t high |
| 67 | $kl/r > 150$ |

| Error Number | Description |
|--------------|---|
| 68 | $kl/r > 250$ |
| 69 | $l/r > 500$ |
| 70 | Unequal legs |
| 71 | $N_{ue} * N > N_{cr}$ |
| 72 | $1/r > 5.87 * r_y * E / F_y$ |
| 73 | $kl/r > 180$ (IS 3.7, Table 3.1) |
| 74 | $kl/r > 250$ (IS 3.7, Table 3.1) |
| 75 | $l/r > 400$ (IS 3.7, Table 3.1) |
| 76 | Signa_ac, cal $> 0.6 * f_{cc}$ (Excessive amplification) (IS 7.1.1) |

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