Autodesk®
Robot™ Structural Analysis Professional

VERIFICATION MANUAL

FOR AMERICAN CODES

March 2014

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INTRODUCTION

This verification manual contains numerical examples for elements of structures prepared and originally calculated by **Autodesk Robot Structural Analysis Professional version 2013**. The comparison of results is still valid for the next versions.

The most of the examples have been taken from handbooks that include benchmark tests covering fundamental types of behaviour encountered in structural analysis. Benchmark results (signed as “Handbook”) are recalled, and compared with results of Autodesk Robot Structural Analysis Professional (signed further as “Robot”).

Each example contains the following parts:

- title of the problem
- specification of the problem
- Robot solution of the problem
- outputs with calculation results and calculation notes
- comparison between Robot results and exact solution
- conclusions.

STEEL

1. ANSI/AISC 360-05 March 9, 2005

IMPLEMENTED CHAPTERS of ANSI/AISC 360-05

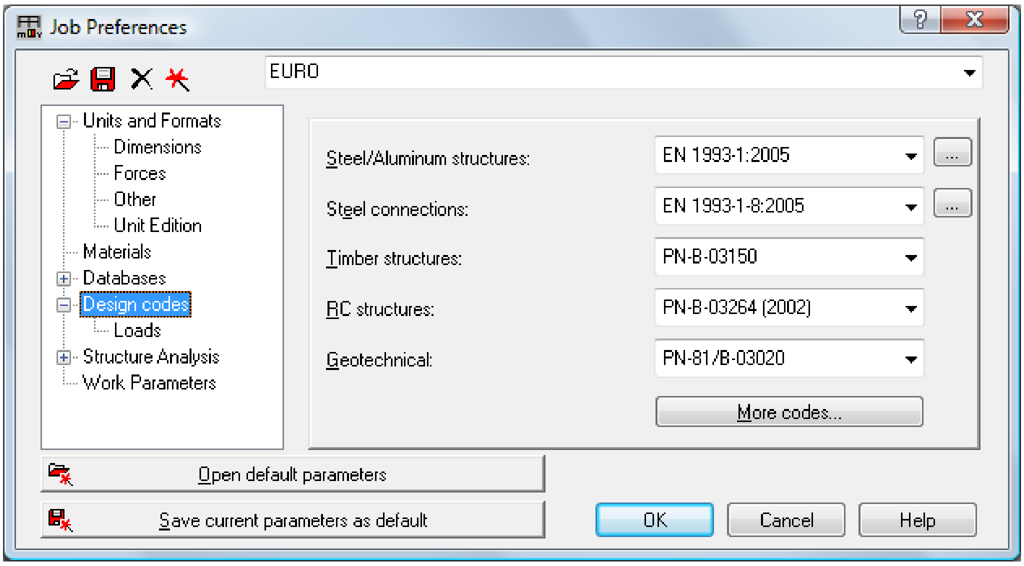
List of Specification for Structural Steel Buildings ANSI/AISC 360-05 chapters, implemented to Robot program:

1. Classification of sections for local buckling - § B.4 and Table B.4.1
2. Design of members for tension- § D
3. Design of members for compression - § E
4. Compressive strength for flexural buckling of members without slender elements - § E3
5. Compressive strength for torsional and flexural-torsional buckling of members without slender elements - § E4
6. Single-angle compression members - § E5
7. Members with slender elements - § E7
8. Design of members for flexure - § F
9. Doubly symmetric compact I-shaped members and channels bent about their major axis – § F2
   Doubly symmetric i-shaped members with compact webs and noncompact or slender flanges bent about their major axis - § f3
   Other I-shaped members with compact or noncompact webs bent about their major - § F4
   Doubly symmetric and singly symmetric i-shaped members with slender webs bent about their major axis - § F5
   I-shaped members and channels bent about their minor axis - § F6
   Square and rectangular hss and box-shaped members - § F7
   Round HSS - § F8
   Tees and double angles loaded in the plane of symmetry - § F9
   Single angles - § F10
   Rectangular bars and rounds - § F11
   Unsymmetrical shapes - § F12
10. Design of members for shear - § G
    Members with unstiffened or stiffened webs - § G.2
    Tension field action - § G.3
    Single angles - § G.4
    Rectangular hss and box members - § G.5
    Round hss - § G.6
    Weak axis shear in singly and doubly symmetric shapes - § G.7
11. Design of members for combined forces and torsion - § H
    Doubly and singly symmetric members subject to flexure and axial force - § H1
    Unsymmetric and other members subject to flexure and axial force - § H2
    Members under torsion and combined torsion, flexure, shear and/or axial force - §H3

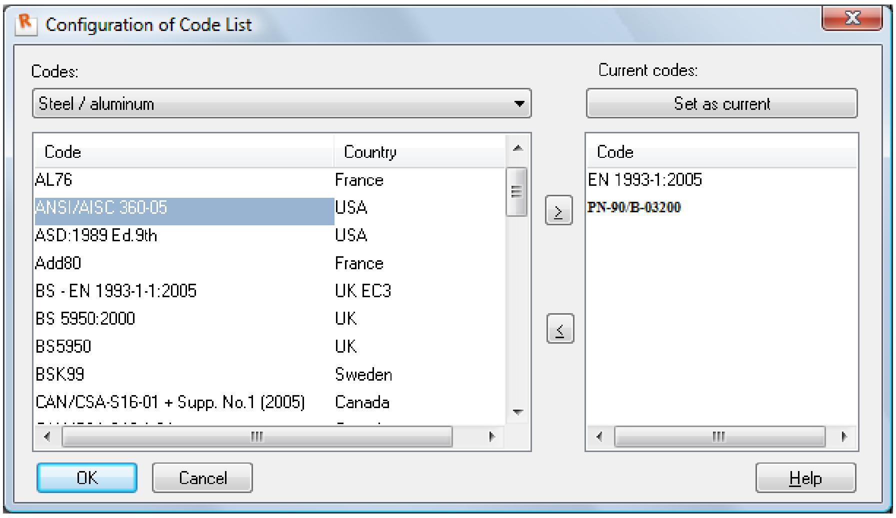
GENERAL REMARKS

A. Job Preferences

If you make first step in Robot program → specify your job preferences in JOB PREFERENCES dialog box (click Menu/ Tools/ Job Preferences). Default JOB PREFERENCES dialog box opens:

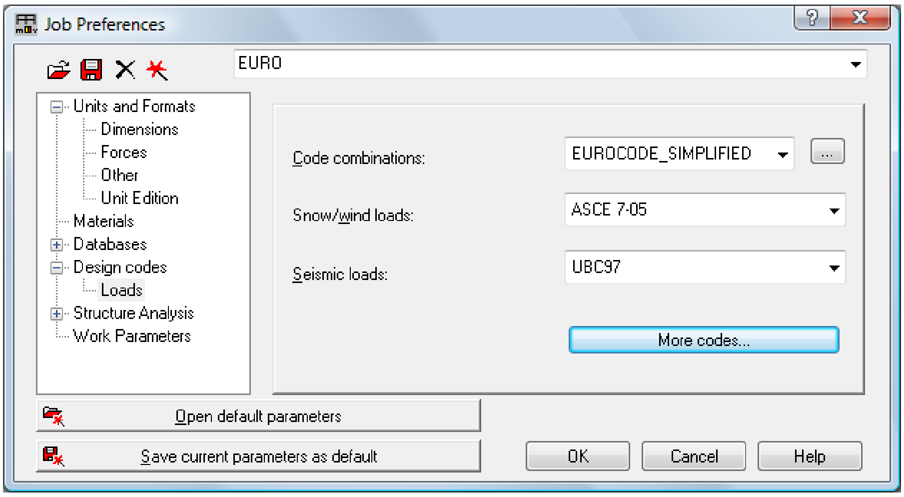


You can define a new type of Job Preferences to make it easier for future.
First of all, make selection of documents and parameters appropriate for USA condition from tabs of the list view in JOB PREFERENCES dialog box.
For example to choose code, first click *Design codes* tab from left list view, then select code from *Steel/Aluminum structures* combo-box or press *More codes* button which opens *Configuration of Code List:*

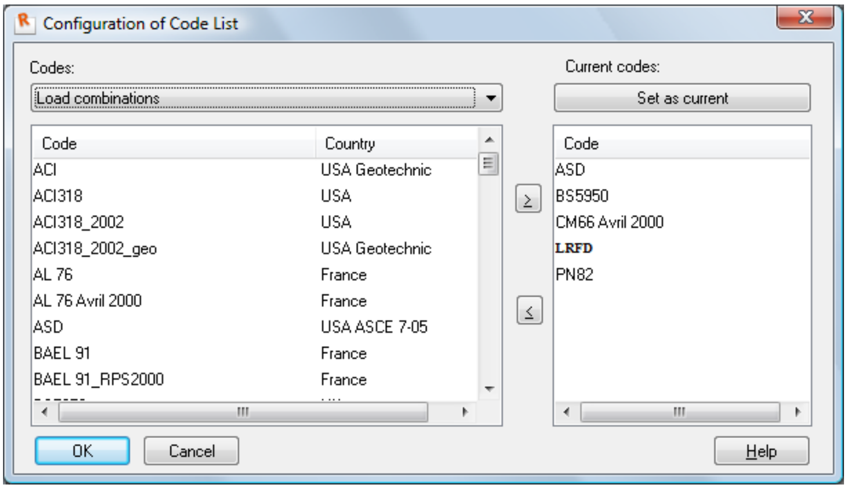


Set ANSI/AISC code as the *current* code. Press OK.

To choose code combination first click *Loads* tab from left list view in JOB PREFERENCES dialog box,

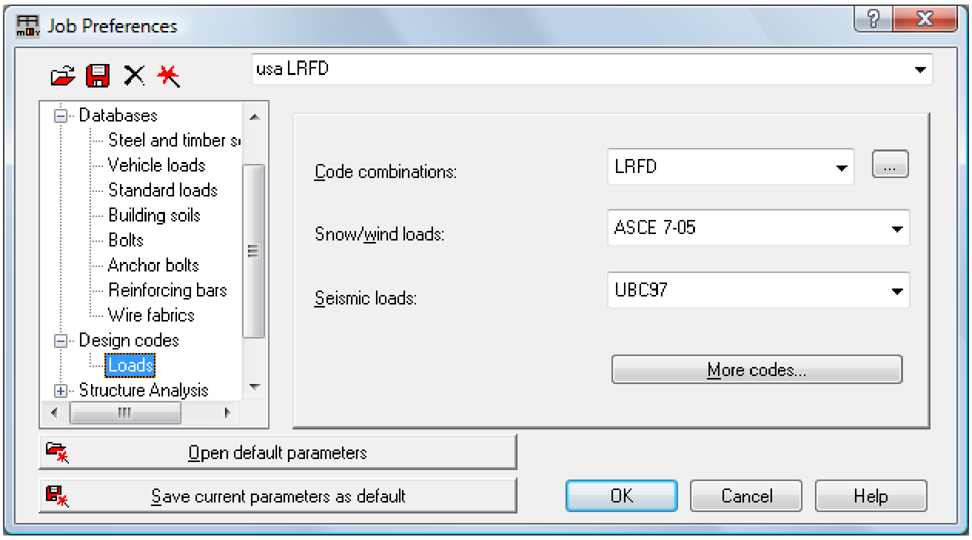


then select code from *Code combinations* combo-box or press *More codes* button which opens *Configuration of Code List.*
Pick *Load combinations* from combo box*.* The new list view appears:

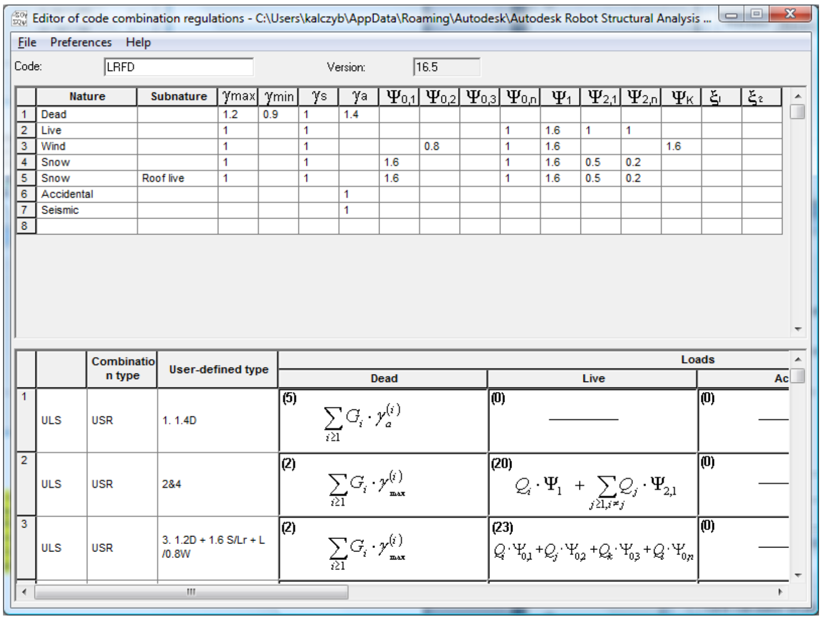


Set ASD and LRFD on the right list of the box. If LRFD code is selected as the *current* code the Job Preferences can be named e.g.: "*usa LRFD" .*

After the job preferences decisions are set, press *Save Job Preferences* icon in JOB PREFERENCES dialog box. It opens *Save Job Preferences* dialog box.
Type a new name e.g. ***" usa LRFD"*** and save it. The new name appears in the combo-box.
Press OK button.



You can check load combination regulations by pressing right button next to *Code combinations* combo-box in *Loads* tab JOB PREFERENCES dialog box. It opens proper *Editor of code combination regulations* dialog box.



B. Calculation method

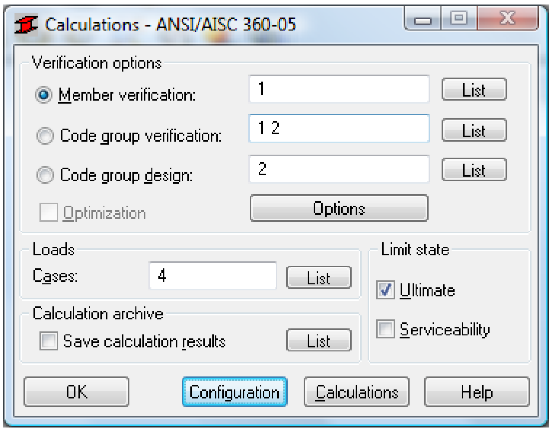
American code ANSI /AISC 360-05 gives two verification options: LRFD and ASD. In Robot program you must always manually specify:

1. calculation method
2. load code combination -> appropriate for calculation method

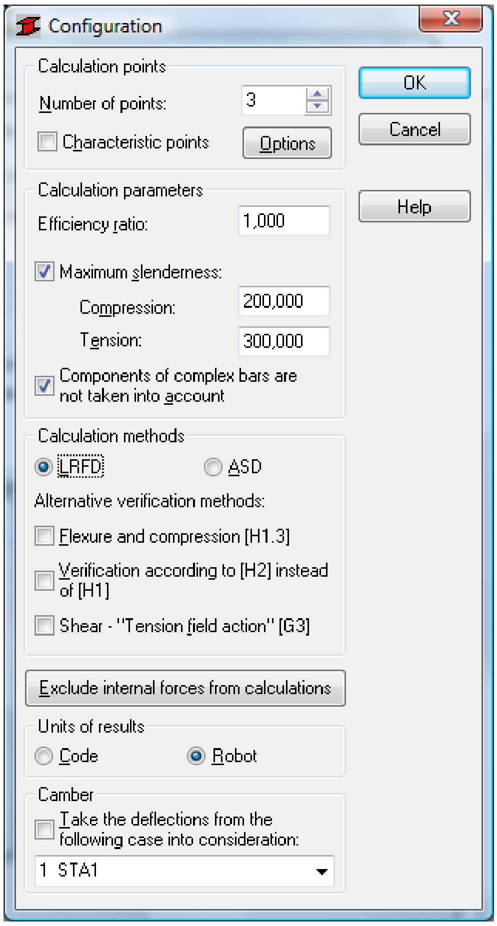
ad.1 calculation method

Calculation method (LRFD or ASD) can be chosen on *Steel /Aluminum Design* layout.

Press the *Configuration* button in CALCULATIONS dialog box.

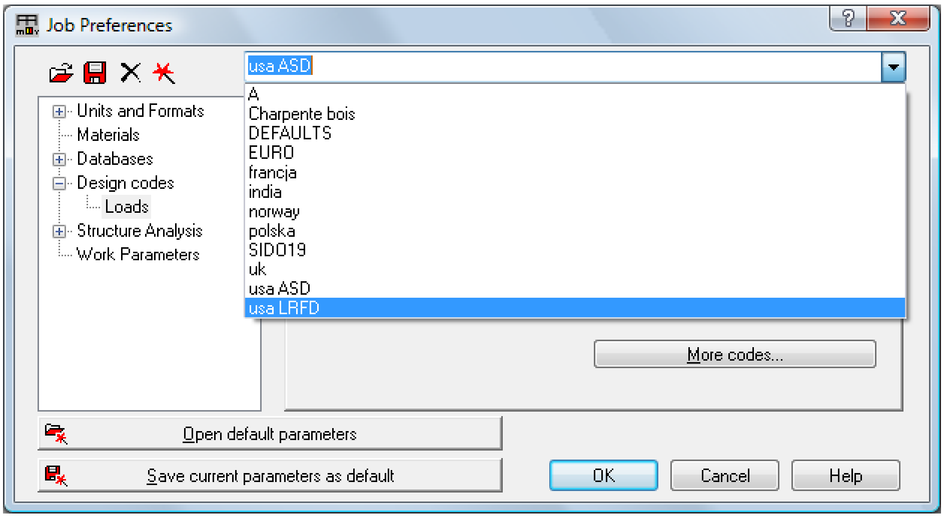


Here you can choose only calculation method.



ad.2a load code combination – basic approach

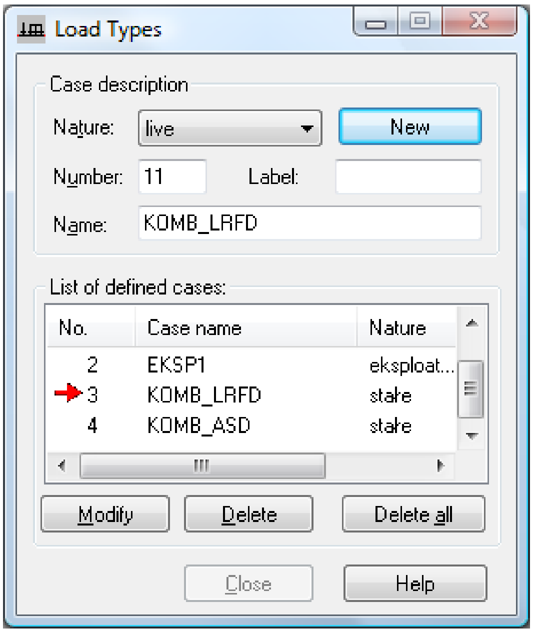
To specify load code combination (LRFD or ASD) appropriate for calculation method, click Menu/ Tools/ Job Preferences. JOB PREFERENCES dialog box opens.
Select earlier prepared job preferences (as defined in *Section A*.) by clicking its name from combo-box. In following dialog box ***usa ASD*** job preferences will change to ***usa LRFD*** one.



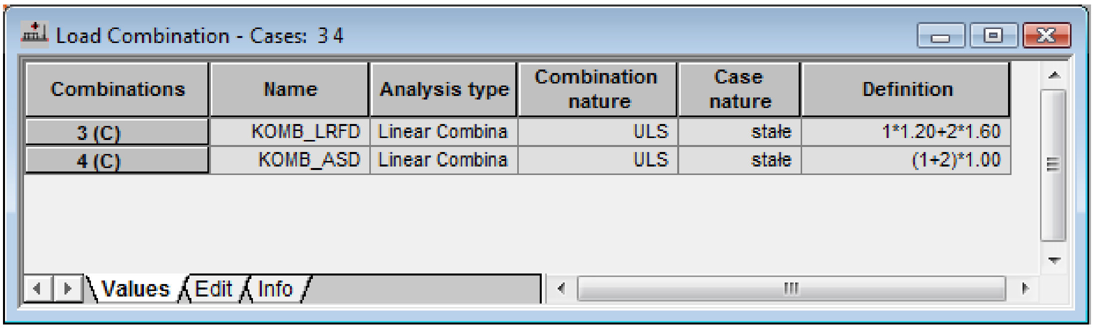
By pressing OK button you accept chosen job preferences for a current task.

ad.2b load code combination - alternative (tricky-easy) approach

Start in *Loads* layout. Here, you can prepare load combination for both calculation method for further using (for member verification). Create manually LRFD load combination and ASD load combination in *Load Types* dialog box.



In this case, you can use in verification, appropriate load combination corresponding to calculation method:



VERIFICATION EXAMPLE 1
- Design of members for compression

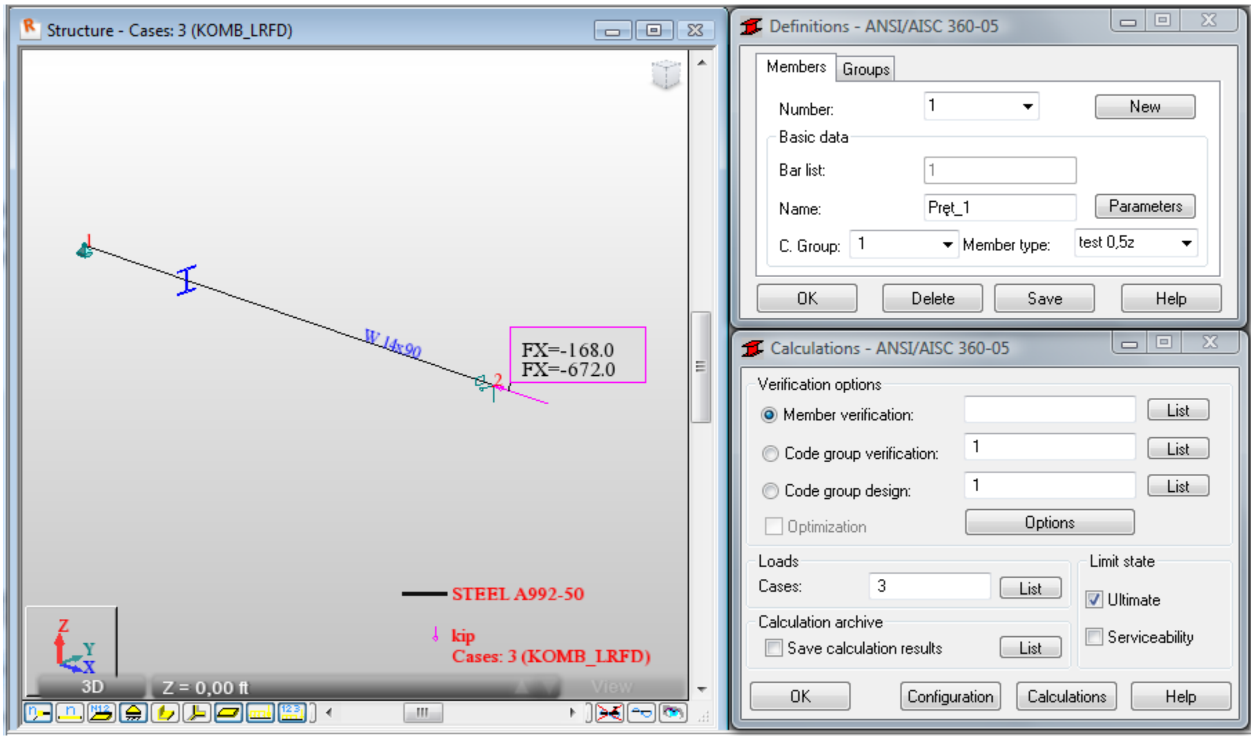
Example taken from AISC Steel Construction Manual v13.0
AISC Design Examples

TITLE:

Example E.1d – W-Shape Available Strength Calculation

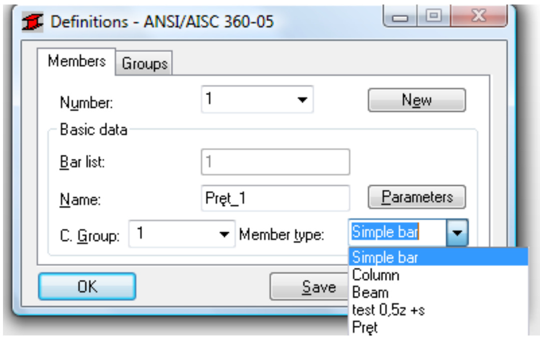
SPECIFICATION:

Select an ASTM A992 (*Fy* = 50 ksi) W14x90 bar to carry an axial dead load of 140 kips and live load of 420 kips. Assume the design member is 30 feet long, is pinned top and bottom in both axes, and is laterally braced about the z-z axis and torsionally braced at the midpoint.
Verify the strength of defined compression member.
You can choose ASD or LFRD calculation method.

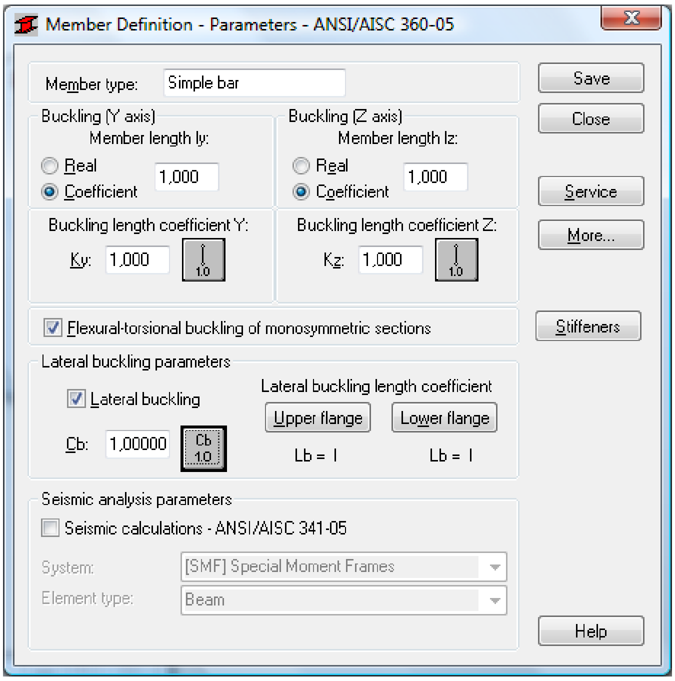


SOLUTION:

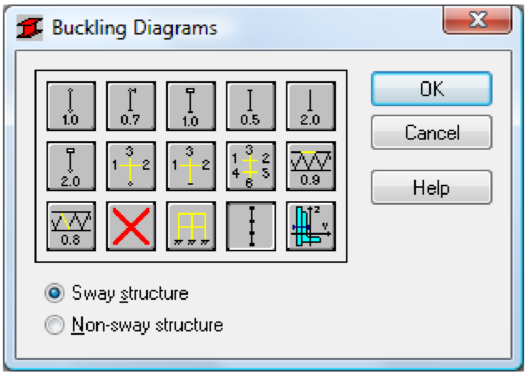
You must remember to specify appropriate (LRSD or ASD) load code combination in JOB PREFERENCES dialog box (click Menu/Tools/Job Preferences).
In DEFINITIONS dialog box define a new type of member, laterally braced about the *z-z* axis and torsionally braced at the midpoint. It can be set in *Member type* combo-box. Pre-defined type of member "*simple bar*" may be initially opened.



For choosen member type (here "*simple bar*"), press the *Parameters* button on *Members* tab, which opens MEMBER DEFINITION – PARAMETERS dialog box.

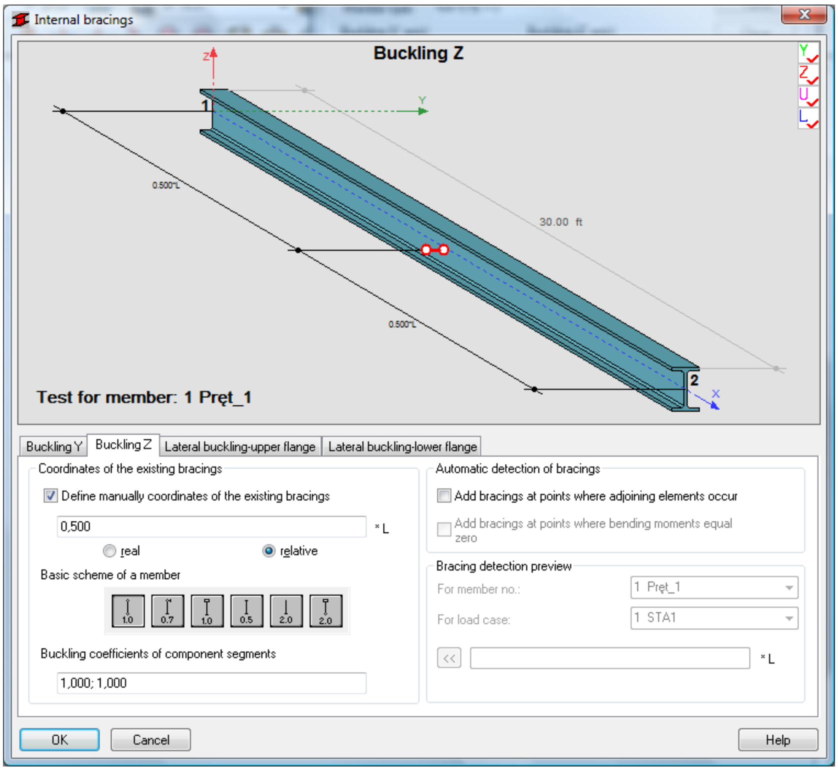


Type a new name in the *Member type* editable field. Change parameters to meet initial data requirements of the structure. In this particular compression case define buckling z-z parameters. Press *Buckling length coefficient Z* icon which opens BUCKLING DIAGRAMS dialog box.

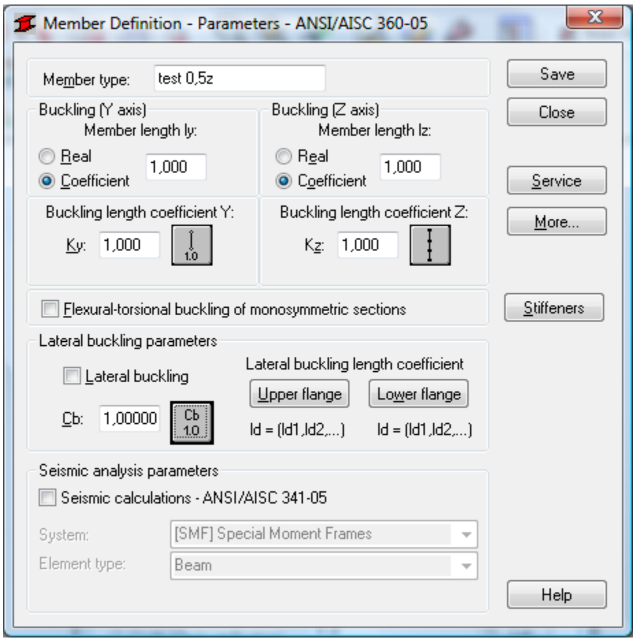


Click second to last icon.

The new dialog box *INTERNAL BRACING* will appear with active *Buckling Z* tab:

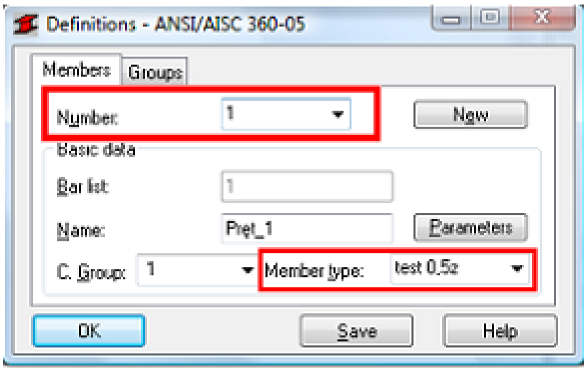


In *Buckling Z* tab define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. Press OK.
Save the newly-created member type, e.g. *"test 0,5z":*



Number of the member must be assigned to appropriate name of *Member type.*

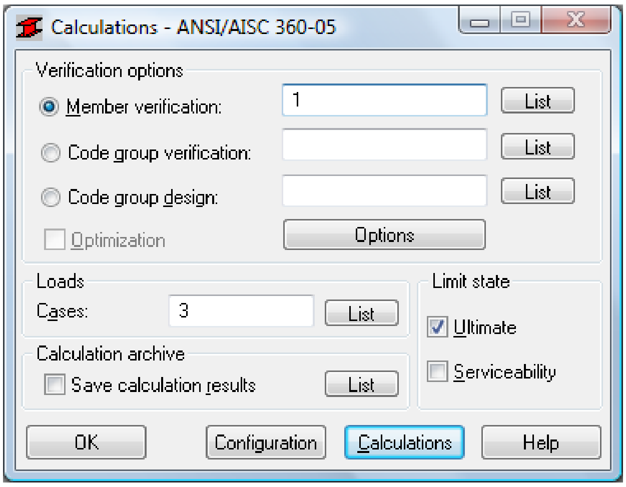
(It is very important when you verify different member types.)



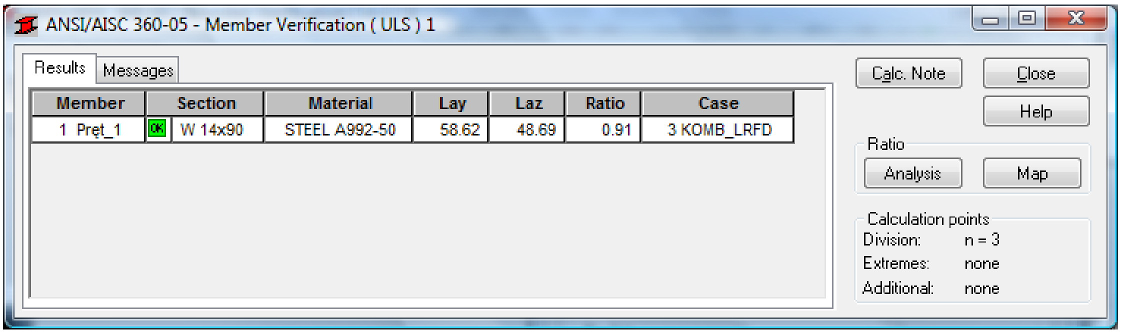
In the CALCULATIONS dialog box set:

-> *Verification option;* here Member Verification,
-> *Loads cases ;* here for LRFD design, only n° 3
-> *Limit state ;* here only Ultimate Limit state will be analyzed,so switch off *Limit stat –Serviceability*.

Now, start calculations by pressing *Calculations* button.

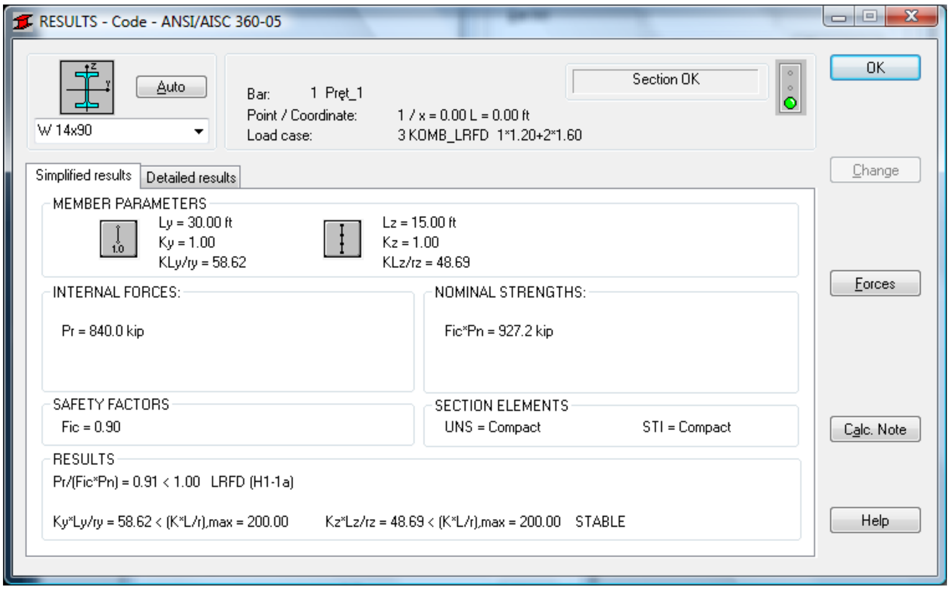


MEMBER VERIFICATION dialog box with most significant results data will appear on screen.

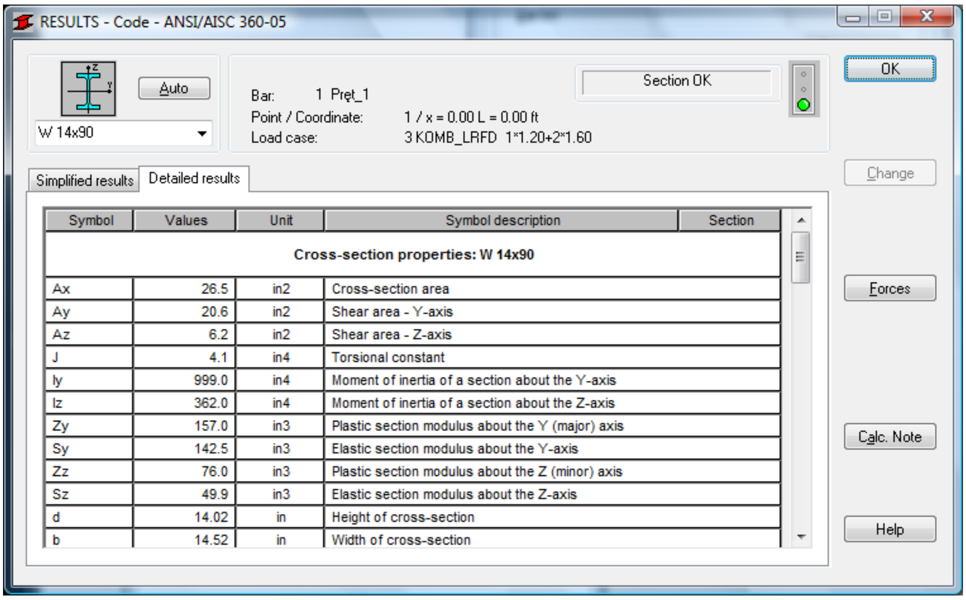


Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS windows are presented below.

Simplified results tab



Detailed results tab



Pressing the *Calc.Note* button in "RESULTS –Code" dialog box opens the printout note for the analyzed member. You can obtain *Simplified results printout* or *Detailed results printout.* It depends on which tab is active.
The printout note view of *Simplified results* is presented below.

RESULTS for LRFD method:

a) In the first step W14x90 section was considered. The results are presented below.

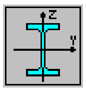
STEEL DESIGN

CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 Pręt_1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 3 KOMB_LRFD 1*1.20+2*1.60

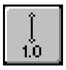
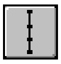
MATERIAL:
STEEL A992-50 Fy = 50.00 ksi Fu = 65.00 ksi E = 29000.00 ksi



SECTION PARAMETERS: W 14x90

d=14.02 in	Ay=20.6 in2	Az=6.2 in2	Ax=26.5 in2
b=14.52 in	Iy=999.0 in4	Iz=362.0 in4	J=4.1 in4
tw=0.44 in	Sy=142.5 in3	Sz=49.9 in3	
tf=0.71 in	Zy=157.0 in3	Zz=76.0 in3	

MEMBER PARAMETERS:

	
Ly = 30.00 ft	Lz = 15.00 ft
Ky = 1.00	Kz = 1.00
KLy/ry = 58.62	KLz/rz = 48.69

INTERNAL FORCES:
Pr = 840.0 kip

NOMINAL STRENGTHS:
Fic*Pn = 927.2 kip

SAFETY FACTORS
Fic = 0.90

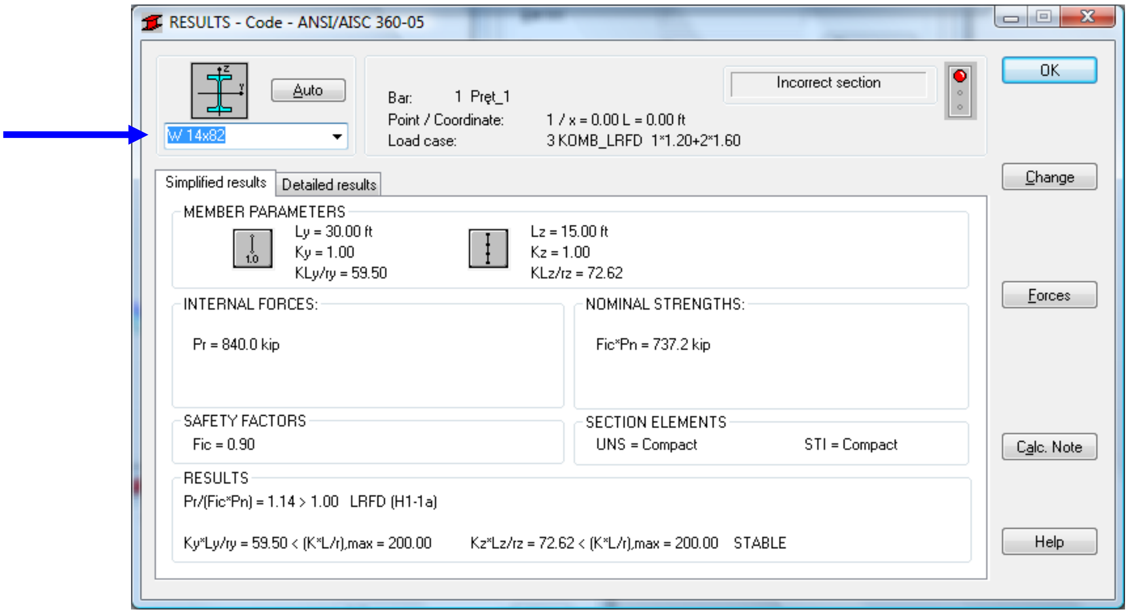
SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pr/(Fic*Pn) = 0.91 < 1.00 LRFD (H1-1a) Verified
Ky*Ly/ry = 58.62 < (K*L/r),max = 200.00 Kz*Lz/rz = 48.69 < (K*L/r),max = 200.00 STABLE

Section OK !!!

b) From economical reason try to check the next lighter W section.

Being still in *RESULTS- CODE* dialog box, type W 14x82 in the editable field below drawing of section and press ENTER. Calculations (and results) are refreshed instantly.



The results for new selected section are presented below.

STEEL DESIGN

CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 Pret_1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

---

LOADS:
Governing Load Case: 3 KOMB_LRFD 1*1.20+2*1.60

MATERIAL:
STEEL A992-50 Fy = 50.00 ksi Fu = 65.00 ksi E = 29000.00 ksi

SECTION PARAMETERS: **W 14x82**

d=14.31 in	Ay=17.3 in2	Az=7.3 in2	Ax=24.1 in2
b=10.13 in	Iy=882.0 in4	Iz=148.0 in4	J=5.1 in4
tw=0.51 in	Sy=123.3 in3	Sz=29.2 in3	
tf=0.85 in	Zy=139.0 in3	Zz=45.0 in3	

MEMBER PARAMETERS:

Ly = 30.00 ft	Lz = 15.00 ft
Ky = 1.00	Kz = 1.00
KLy/ry = 59.50	KLz/rz = 72.62

INTERNAL FORCES: Pr = 840.0 kip

NOMINAL STRENGTHS: Fic*Pn = 737.2 kip

SAFETY FACTORS Fic = 0.90

SECTION ELEMENTS: UNS = Compact STI = Compact

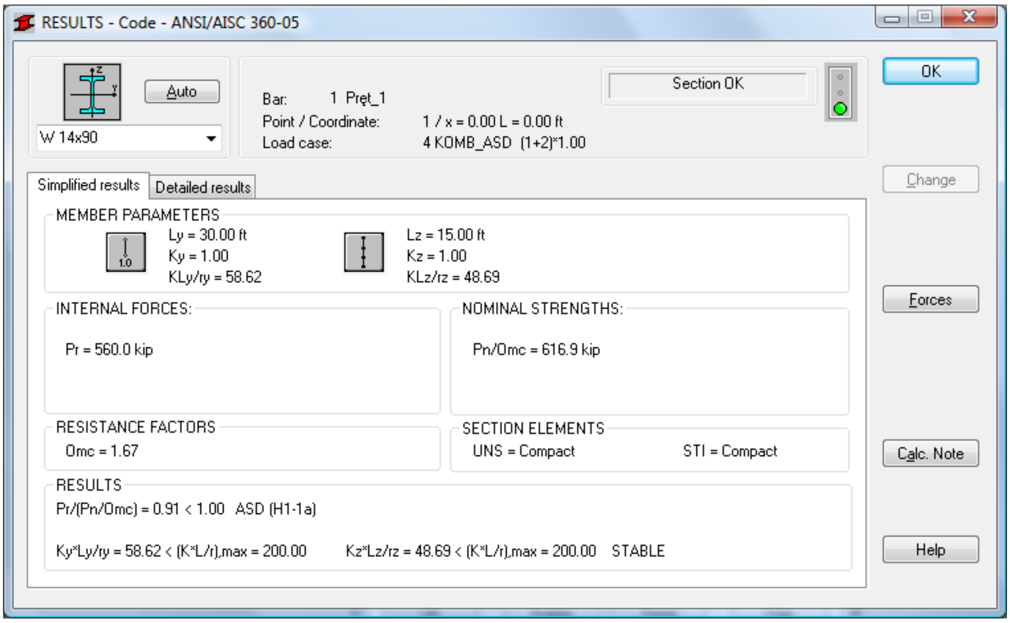
VERIFICATION FORMULAS:
Pr/(Fic*Pn) = 1.14 > 1.00 LRFD (H1-1a) Not verified
Ky*Ly/ry = 59.50 < (K*L/r),max = 200.00 Kz*Lz/rz = 72.62 < (K*L/r),max = 200.00 STABLE

Incorrect section !!!

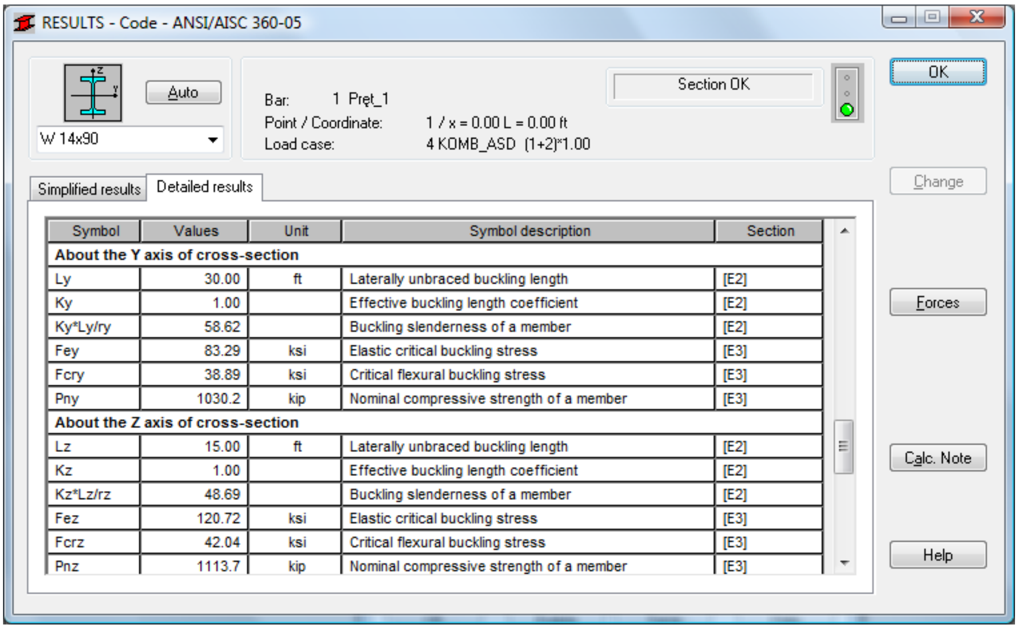
RESULTS for ASD method:

W14x90 was considered. The results are presented below.

Simplified results tab



Detailed results tab



Symbol	Values	Unit	Symbol description	Section
About the Y axis of cross-section				
Ly	30.00	ft	Laterally unbraced buckling length	[E2]
Ky	1.00		Effective buckling length coefficient	[E2]
Ky*Ly/ry	58.62		Buckling slenderness of a member	[E2]
Fey	83.29	ksi	Elastic critical buckling stress	[E3]
Fcry	38.89	ksi	Critical flexural buckling stress	[E3]
Pny	1030.2	kip	Nominal compressive strength of a member	[E3]
About the Z axis of cross-section				
Lz	15.00	ft	Laterally unbraced buckling length	[E2]
Kz	1.00		Effective buckling length coefficient	[E2]
Kz*Lz/rz	48.69		Buckling slenderness of a member	[E2]
Fez	120.72	ksi	Elastic critical buckling stress	[E3]
Fcrz	42.04	ksi	Critical flexural buckling stress	[E3]
Pnz	1113.7	kip	Nominal compressive strength of a member	[E3]

The printout note view of *Simplified results* for ASD is presented below.

STEEL DESIGN

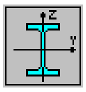
CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 Pręt_1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

---

LOADS:
Governing Load Case: 4 KOMB_ASD (1+2)*1.00

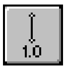
MATERIAL:
STEEL A992-50 Fy = 50.00 ksi Fu = 65.00 ksi E = 29000.00 ksi

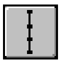


SECTION PARAMETERS: W 14x90

d=14.02 in	Ay=20.6 in2	Az=6.2 in2	Ax=26.5 in2
b=14.52 in	Iy=999.0 in4	Iz=362.0 in4	J=4.1 in4
tw=0.44 in	Sy=142.5 in3	Sz=49.9 in3	
tf=0.71 in	Zy=157.0 in3	Zz=76.0 in3	

MEMBER PARAMETERS:





Ly = 30.00 ft	Lz = 15.00 ft
Ky = 1.00	Kz = 1.00
KLy/ry = 58.62	KLz/rz = 48.69

INTERNAL FORCES:
Pr = 560.0 kip

NOMINAL STRENGTHS:
Pn/Omc = 616.9 kip

RESISTANCE FACTORS
Omc = 1.67

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pr/(Pn/Omc) = 0.91 < 1.00 ASD (H1-1a) Verified
Ky*Ly/ry = 58.62 < (K*L/r),max = 200.00 Kz*Lz/rz = 48.69 < (K*L/r),max = 200.00 STABLE

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
For W14x90, **LRFD** Fic=0.90 1. P_r - Required compressive strength [kips] 2. P_n - Design compressive strength [kips] P_r < (Fic*P_n)	 840,0 1030,2 840 < 927,2	 840 1030 840< 928
For W14x90, **ASD** Omc =1.67 1. P_r - Required compressive strength [kips] 2. P_n - Design compressive strength [kips] P_r < (P_n/Omc))	 560,0 1030,2 560 < 616,9	 560 1030 560 < 618

CONCLUSIONS:

Underline value, from handbook, are wrong
(Fic*P_n) = 0,9 * 1030 = 927,0 not 928
P_n/Omc =1030 / 1,67 = 616,8 not 618 ,

The small differences are caused by different accuracy of parameters in calculations.

VERIFICATION EXAMPLE 2
- Lateral-torsional buckling of beams

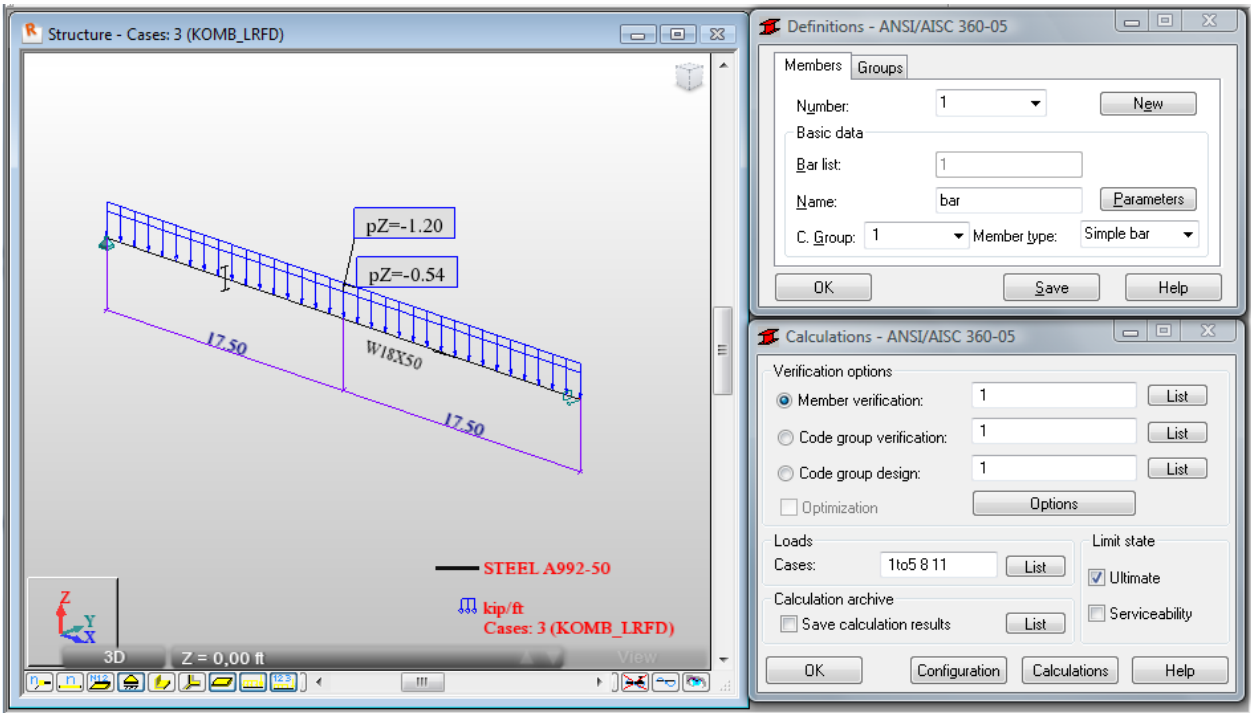
Example taken from AISC Steel Construction Manual v13.0
AISC Design Examples

TITLE:

Example F.1-3b -- W-Shape Flexural Member Design in Strong-Axis Bending, Braced at Midspan

SPECIFICATION:

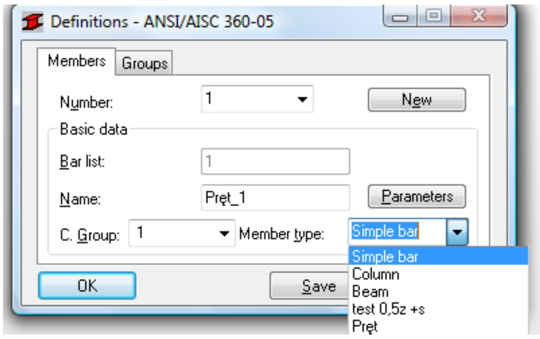
Verify the strength of the ASTM A992 W18×50 beam with a simple span of 35 feet. The beam is braced at the ends and center point. The nominal loads are a uniform dead load of 0.45 kip/ft and a uniform live load of 0.75 kip/ft.
You can choose ASD or LFRD calculation method.



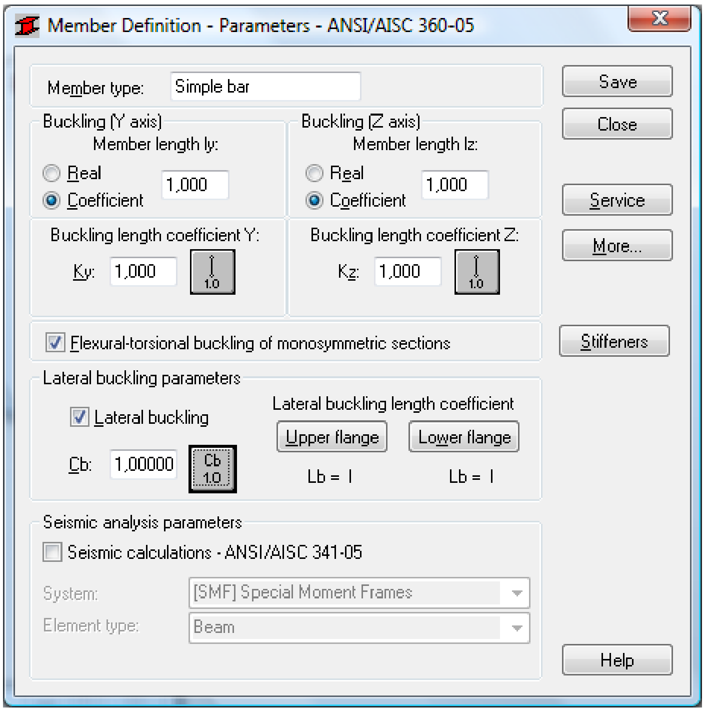
SOLUTION:

You must remember to specify appropriate (LRSD or ASD) load code combination in JOB PREFERENCES dialog box (click Menu/Tools/Job Preferences).

In DEFINITIONS dialog box define a new type of member, laterally braced about the *z-z* axis and torsionally braced at the midpoint. It can be set in *Member type* combo-box. Pre-defined type of member "*simple bar*" may be initially opened.

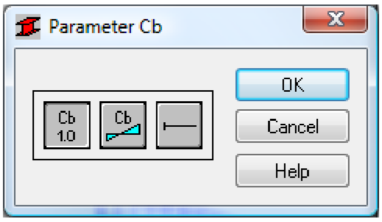


For choosen member type, press the *Parameters* button on *Members* tab.
It opens MEMBER DEFINITION – PARAMETERS dialog box.



Type a new name in the *Member type* editable field. Then change parameters to meet initial data requirements of the structure. In this particular bending case set the following lateral-buckling parameters:

- switch on *Lateral buckling;*
- define appropriate value of Cb by manually entering in editable field or pressing Cb icone which opens PARAMETER Cb dialog box:

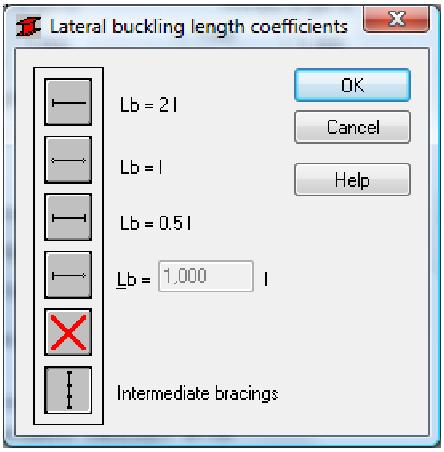


Here, the second icon Cb=f(Mi) was selected.

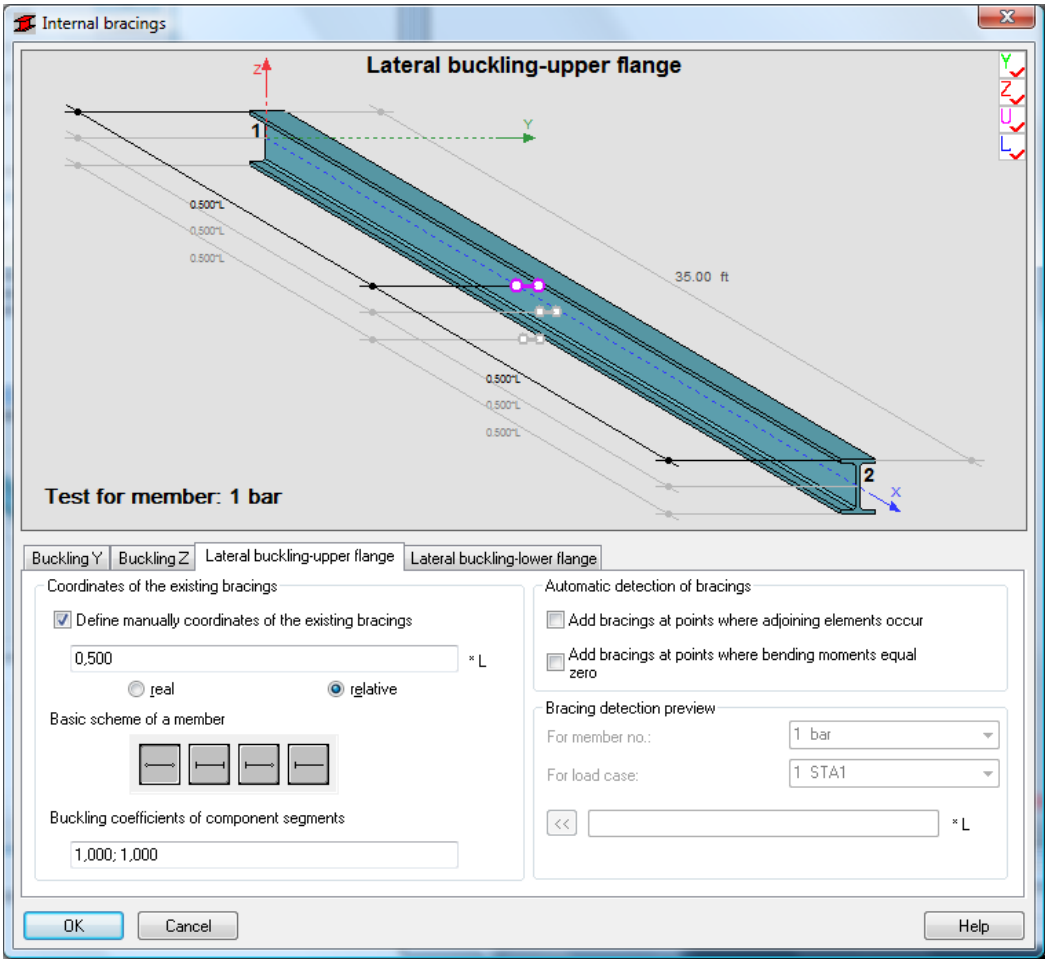
- define bracings for *Lateral buckling* and Buckling *Z.*

To define *Lateral buckling length coefficient* for this structure case, press *Upper flange* icon.

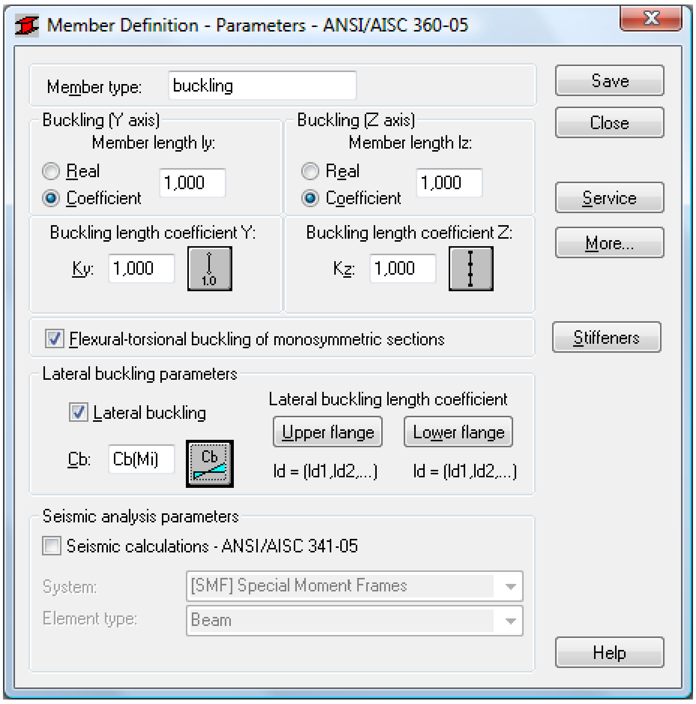
It opens LATERAL BUCKLING LENGTH COEFFICIENTS dialog box.



Click the last icon *Intermediate bracings.*
The new dialog box *INTERNAL BRACINGS* will appear with automatically active *Lateral buckling - Upper flange* tab.
In *INTERNAL BRACINGS* dialog box there are possibilities of defining independent bracings for buckling and lateral buckling of the marked *member type*.
In *Lateral buckling- upper flange* tab, - *lower flange* tab and *Buckling* Z tab define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field.
Press OK.

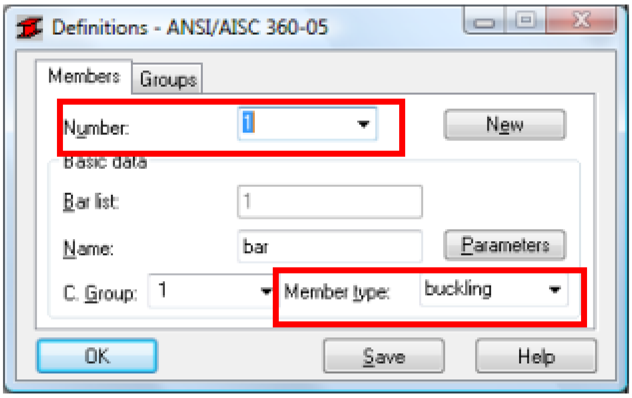


Save the newly-created member type:

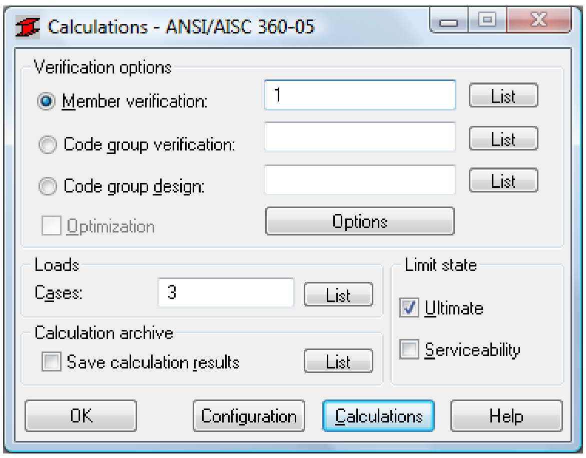


Number of the member must be assigned to appropriate name of *Member type.*

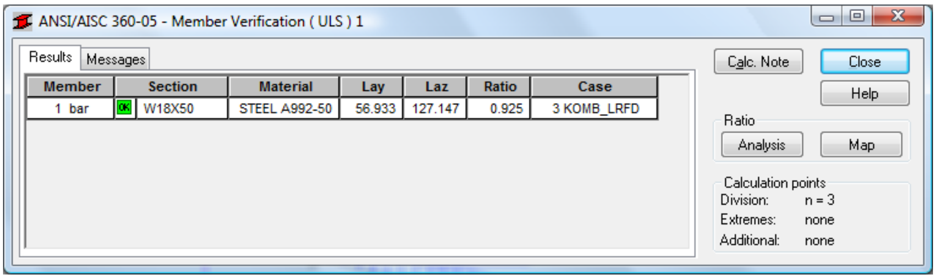
(very importent when you verify different member types.)



In the CALCULATIONS dialog box set:
-> *Verification options ;* here Member Verification,
-> *Loads cases ;* here for LRFD design only n^{o} 3
-> *Limit state ;* here only Ultimate Limit state will be analyzed,so switch off *Limit stat –Serviceability*.

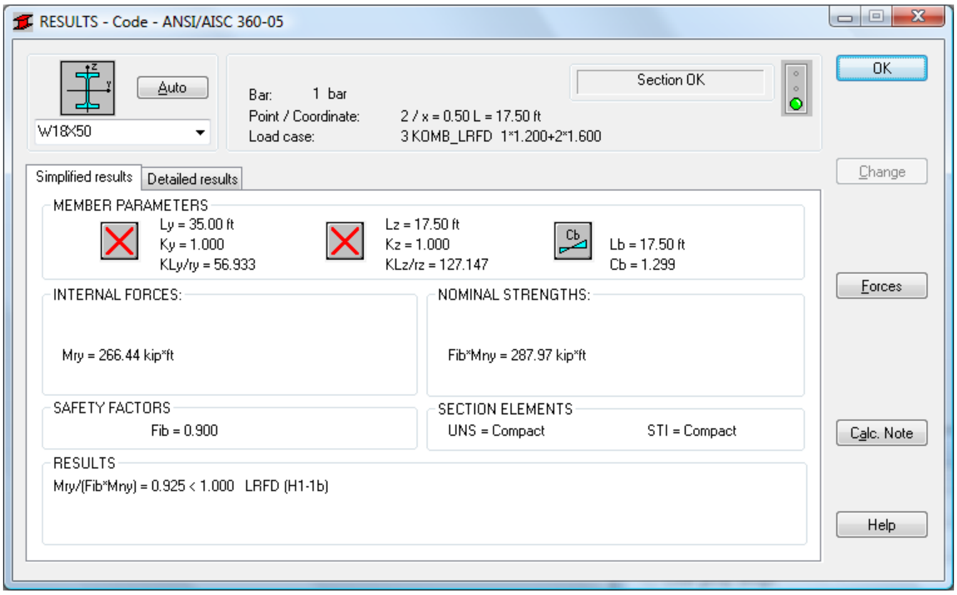


Now, start verifications by pressing
Calculations button.
MEMBER VERIFICATION dialog box with most significant results data will appear on screen.

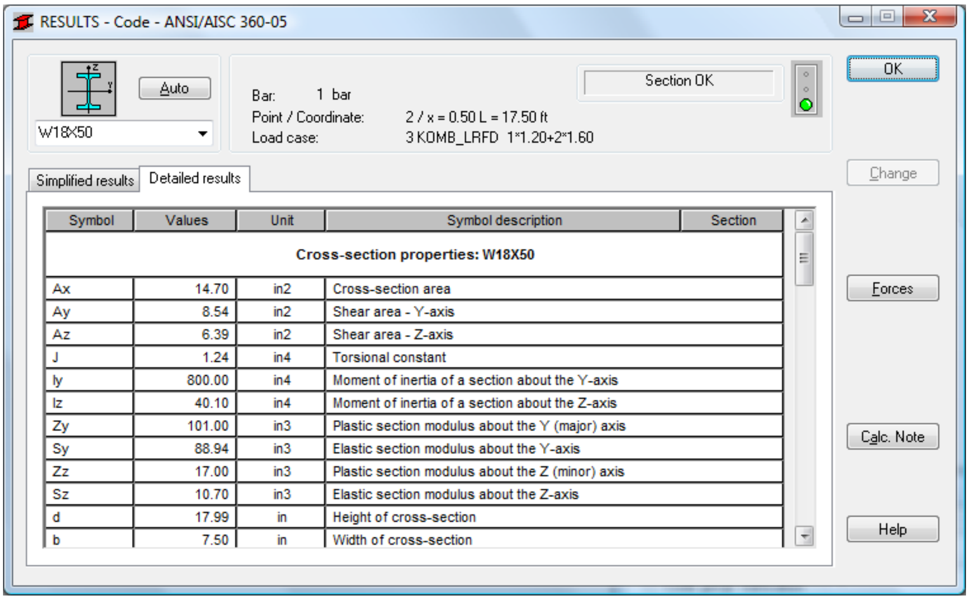


Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS windows are presented below.

Simplified results tab



Detailed results tab



Pressing the *Calc.Note* button in “RESULTS –Code” dialog box opens the printout note for

the analyzed member. You can obtain *Simplified results printout* or *Detailed results printout.*
It depends on which tab is active.
The printout note view of *Simplified results* is presented below.

RESULTS for LRFD method:

STEEL DESIGN

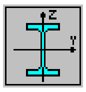
CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 bar **POINT:** 2 **COORDINATE:** x = 0.50 L = 17.50 ft

---

LOADS:
Governing Load Case: 3 KOMB_LRFD 1*1.20+2*1.60

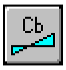
MATERIAL:
STEEL A992-50 Fy = 50.00 ksi Fu = 65.00 ksi E = 29000.00 ksi



SECTION PARAMETERS: W18X50

d=17.99 in	Ay=8.54 in2	Az=6.39 in2	Ax=14.70 in2
b=7.50 in	Iy=800.00 in4	Iz=40.10 in4	J=1.24 in4
tw=0.35 in	Sy=88.94 in3	Sz=10.70 in3	
tf=0.57 in	Zy=101.00 in3	Zz=17.00 in3	

MEMBER PARAMETERS:

Ly = 35.00 ft	Lz = 17.50 ft	
Ky = 1.00	Kz = 1.00	Lb = 17.50 ft
KLy/ry = 56.93	KLz/rz = 127.15	Cb = 1.30

INTERNAL FORCES:
Mry = 266.44 kip*ft

NOMINAL STRENGTHS:
Fib*Mny = 287.97 kip*ft

SAFETY FACTORS
Fib = 0.90

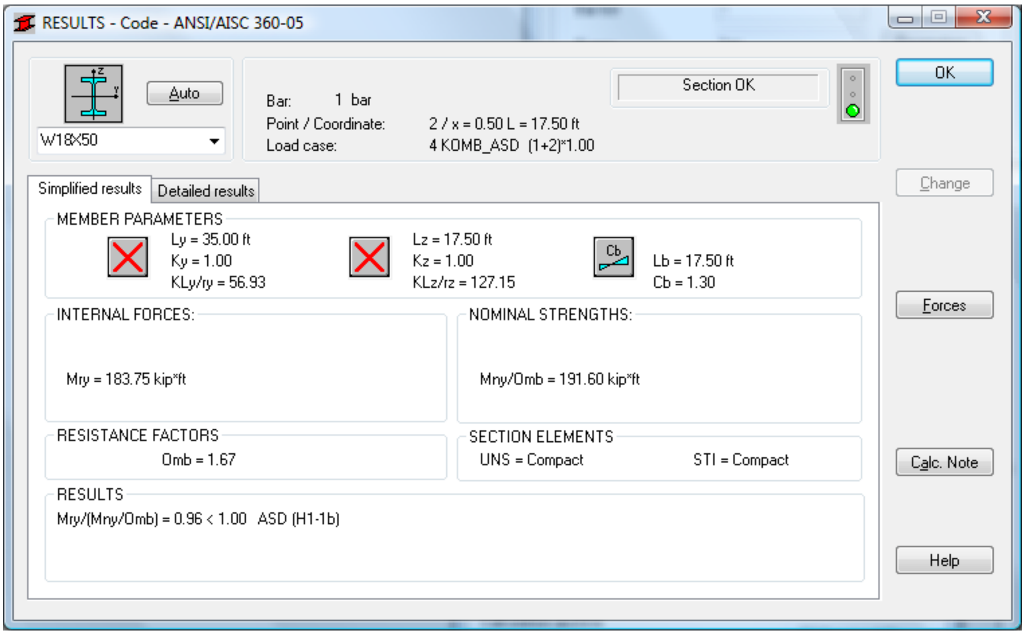
SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Mry/(Fib*Mny) = 0.93 < 1.00 LRFD (H1-1b) Verified

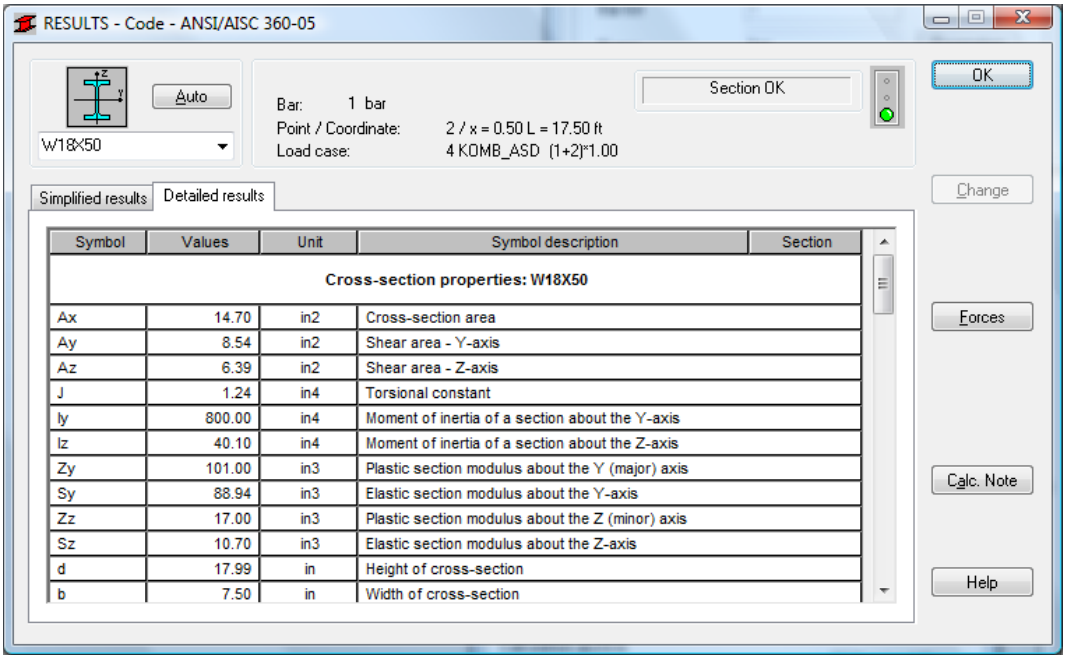
Section OK !!!

RESULTS for ASD method:

Simplified results tab



Detailed results tab



Symbol	Values	Unit	Symbol description	Section
Cross-section properties: W18X50				
Ax	14.70	in2	Cross-section area	
Ay	8.54	in2	Shear area - Y-axis	
Az	6.39	in2	Shear area - Z-axis	
J	1.24	in4	Torsional constant	
Iy	800.00	in4	Moment of inertia of a section about the Y-axis	
Iz	40.10	in4	Moment of inertia of a section about the Z-axis	
Zy	101.00	in3	Plastic section modulus about the Y (major) axis	
Sy	88.94	in3	Elastic section modulus about the Y-axis	
Zz	17.00	in3	Plastic section modulus about the Z (minor) axis	
Sz	10.70	in3	Elastic section modulus about the Z-axis	
d	17.99	in	Height of cross-section	
b	7.50	in	Width of cross-section	

Pressing the *Calc.Note* button in "RESULTS – Code" dialog box opens the printout note for the analyzed member. You can obtain *Simplified results printout* or *Detailed results printout.*
It depends on which tab is active.
The printout note view of *Simplified results* for ASD is presented below.

STEEL DESIGN

CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 bar **POINT:** 2 **COORDINATE:** x = 0.50 L = 17.50 ft

---

LOADS:
Governing Load Case: 4 KOMB_ASD (1+2)*1.00

MATERIAL:
STEEL A992-50 Fy = 50.00 ksi Fu = 65.00 ksi E = 29000.00 ksi

SECTION PARAMETERS: W18X50

d=17.99 in	Ay=8.54 in2	Az=6.39 in2	Ax=14.70 in2
b=7.50 in	Iy=800.00 in4	Iz=40.10 in4	J=1.24 in4
tw=0.35 in	Sy=88.94 in3	Sz=10.70 in3	
tf=0.57 in	Zy=101.00 in3	Zz=17.00 in3	

MEMBER PARAMETERS:

Ly = 35.00 ft	Lz = 17.50 ft	
Ky = 1.00	Kz = 1.00	Lb = 17.50 ft
KLy/ry = 56.93	KLz/rz = 127.15	Cb = 1.30

INTERNAL FORCES: Mry = 183.75 kip*ft

NOMINAL STRENGTHS: Mny/Omb = 191.60 kip*ft

RESISTANCE FACTORS
Omb = 1.67

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Mry/(Mny/Omb) = 0.96 < 1.00 ASD (H1-1b) Verified

Section OK !!!

COMPARISON:

verifications parameters, interaction expression	Robot	Handbook
Cb - Lateral-torsional buckling modification factor Lpy - Limiting laterally unbraced length for the limit state of yielding [ft] Lry - Literally unbraced length for the limit state of inelastic lateral- torsional buckling [ft] FcrLtb - Critical stress (lateral-torsional buckling) [ksi]	1,3 5,83 16,96 43,17	1,3 5,83 17,0 43,2
LRFD , Fib=0.90 1. M_{ry} - Required flexural strength [kip*ft] 2. M_{ny} - Design compressive strength [kip*ft] M_{ry} < (Fib* M_{ny})	266,44 319,97 266,44< 287,97	266 320 266< 288
ASD, Omc =1.67 1. M_{ry} - Required flexural strength [kip*ft] 2. M_{ny} - Allowable flexural strength [kip*ft] M_{ry} < (M_{ny} /Omc))	183,75 319,97 183,75< 191,60	184 320 184<192

CONCLUSIONS:

The small differences are caused by different accuracy of parameters in calculations.

VERIFICATION EXAMPLE 3
- Combined compression and bending about both axes

Example taken from AISC Steel Construction Manual v13.0
AISC Design Examples

TITLE:

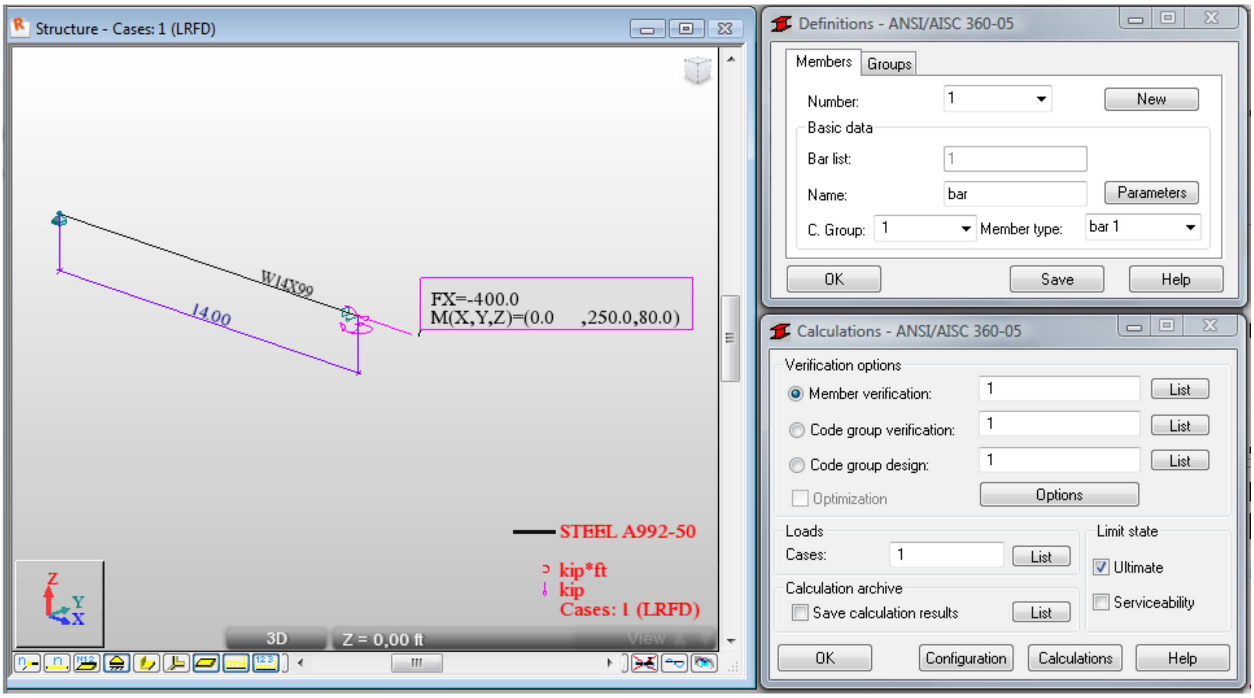
Example H.1 -- W-shape Subjected to Combined Compression and Bending About Both Axes (braced frame).

SPECIFICATION:

Verify if an ASTM A992 W14×99 has sufficient available strength to support the axial forces and moments listed below, obtained from a second order analysis that includes second-order effects. The unbraced length is 14 ft and the member has pinned ends. $KLx = KLy = Lb = 14.0$ ft

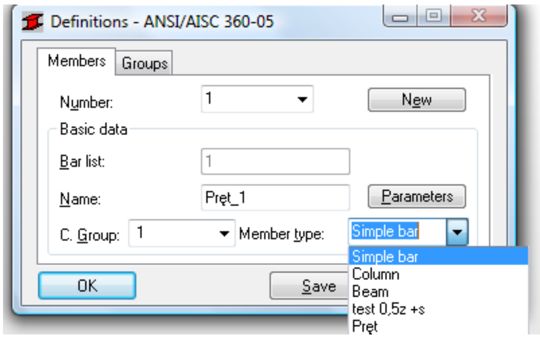
LRFD	ASD
Pu = 400 kips	Pa = 267 kips
Mux = 250 kip-ft	Max = 167 kip-ft
Muy = 80.0 kip-ft	May = 53.3 kip-ft

Material Properties:
ASTM A992 Fy = 50 ksi Fu = 65 ksi

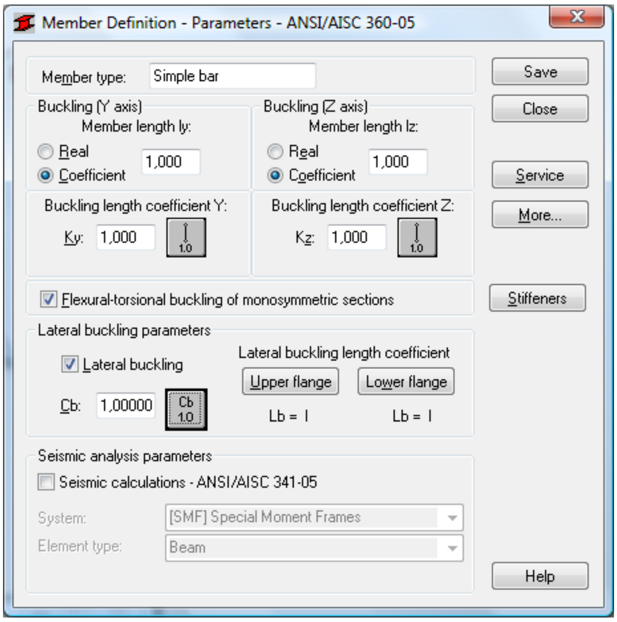


SOLUTION:

You must remember to specify appropriate (LRSD or ASD) load code combination in JOB PREFERENCES dialog box (click Menu/Tools/Job Preferences).
In DEFINITIONS dialog box define a new type of member. It can be set in *Member type* combo-box. Pre-defined type of member "*simple bar*" may be initially opened.

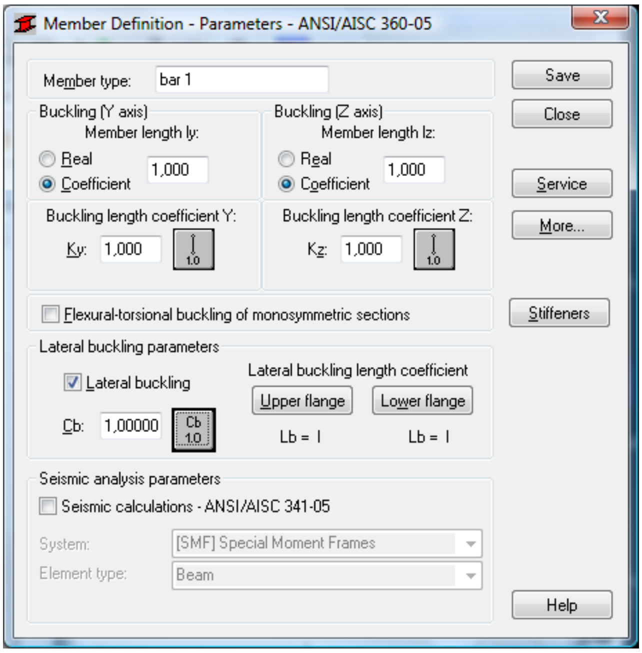


For choosen member type, press the *Parameters* button on *Members* tab.
It opens MEMBER DEFINITION – PARAMETERS dialog box.



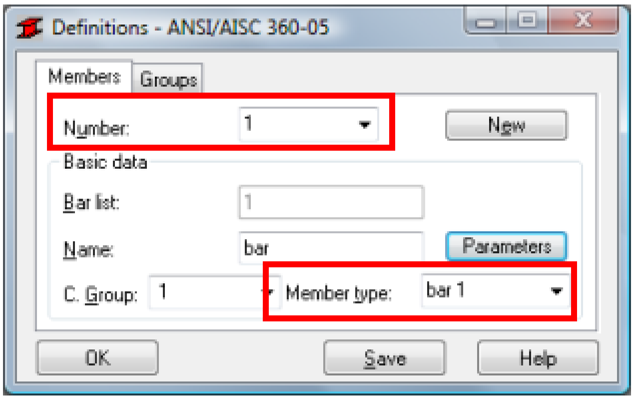
Type a new name in the *Member type* editable field. Then, change parameters to meet initial data requirements of the structure. In this particular load case switch off *Flexural-torsional buckling of monosymetric sections.*

MEMBER DEFINITION–PARAMETERS dialog box defined for verifications looks like:

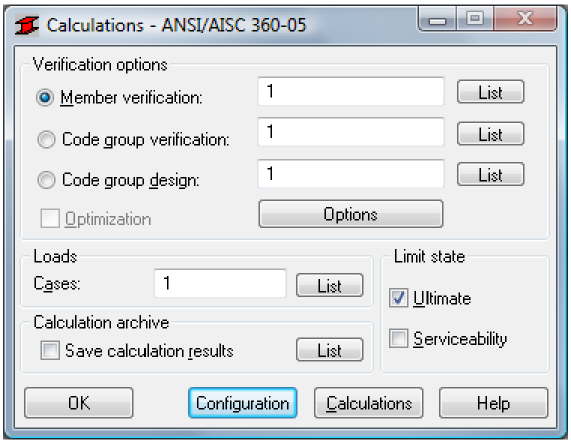


Save the newly-created member type “*bar 1”.*

Number of the member must be assigned to appropriate name of *Member type*
(very importent when you verify different member types.)

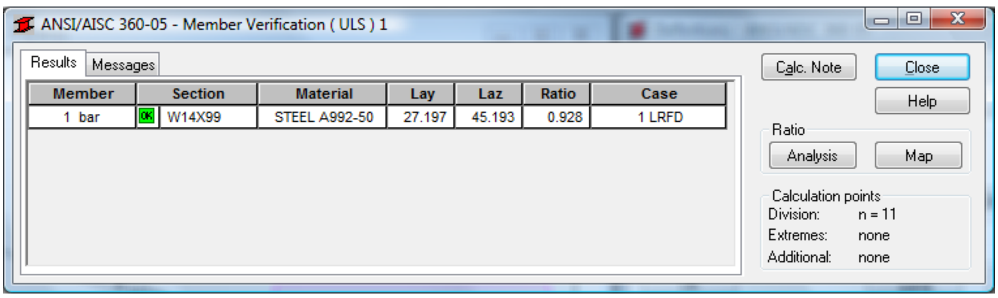


In the CALCULATIONS dialog box set:
-> *Verification options ;* here Member Verification,
-> *Loads cases ;* here for LRFD design only n° 3
-> *Limit state ;* here only Ultimate Limit state will be analyzed,so switch off *Limit stat –Serviceability*.



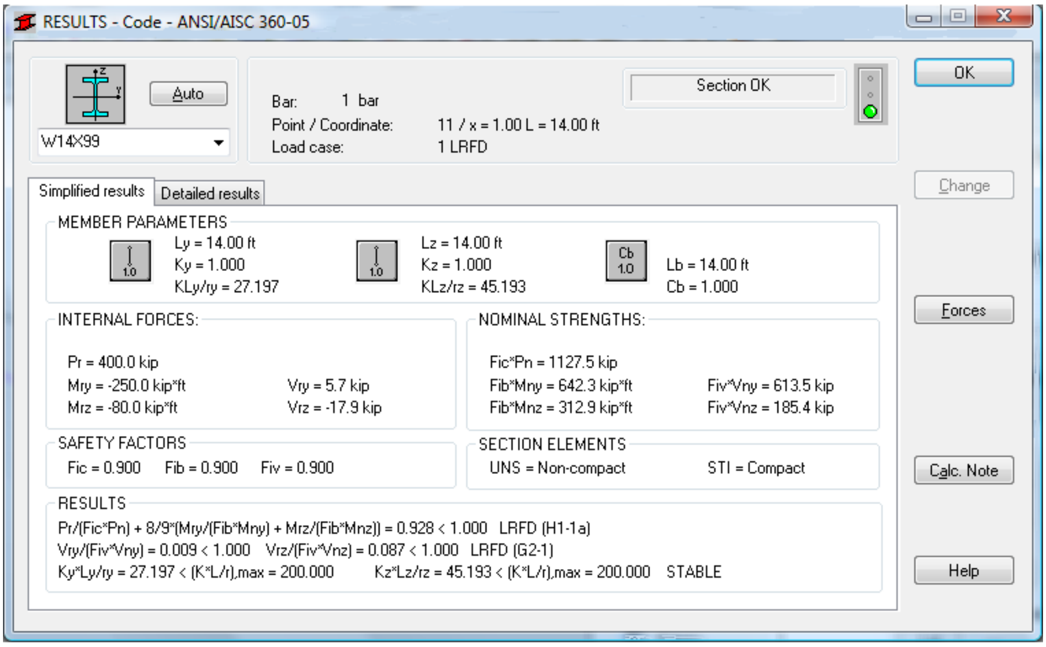
Now, start verifications by pressing *Calculations* button.

MEMBER VERIFICATION dialog box with most significant results data will appear on screen.

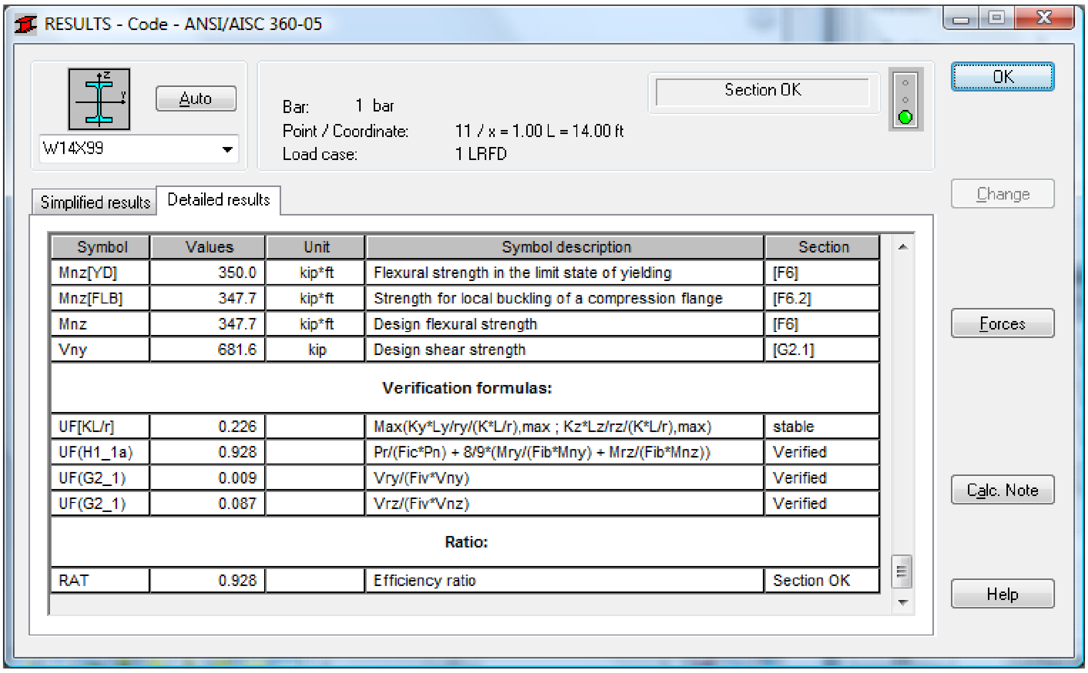


Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS windows are presented below.

Simplified results tab



Detailed results tab



Pressing the *Calc.Note* button in "RESULTS –Code" dialog box opens the printout note for the analyzed member. You can obtain *Simplified results printout* or *Detailed results printout.* It depends on which tab is active.
The printout note view of *Simplified results* is presented below.

RESULTS for LRFD method:

STEEL DESIGN

CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 bar **POINT:** 11 **COORDINATE:** x = 1.00 L = 14.00 ft

---

LOADS:
Governing Load Case: 1 LRFD

MATERIAL:
STEEL A992-50 Fy = 50.0 ksi Fu = 65.0 ksi E = 29000.0 ksi

SECTION PARAMETERS: W14X99

d=14.16 in	Ay=22.721 in2	Az=6.868 in2	Ax=29.090 in2
b=14.57 in	Iy=1110.000 in4	Iz=402.000 in4	J=5.370 in4
tw=0.48 in	Sy=156.780 in3	Sz=55.201 in3	
tf=0.78 in	Zy=173.000 in3	Zz=84.000 in3	

MEMBER PARAMETERS:

Ly = 14.00 ft	Lz = 14.00 ft	
Ky = 1.000	Kz = 1.000	Lb = 14.00 ft
KLy/ry = 27.197	KLz/rz = 45.193	Cb = 1.000

INTERNAL FORCES: / **NOMINAL STRENGTHS:**

Pr = 400.0 kip		Fic*Pn = 1127.5 kip	
Mry = -250.0 kip*ft	Vry = 5.7 kip	Fib*Mny = 642.3 kip*ft	Fiv*Vny = 613.5 kip
Mrz = -80.0 kip*ft	Vrz = -17.9 kip	Fib*Mnz = 312.9 kip*ft	Fiv*Vnz = 185.4 kip

---

SAFETY FACTORS
Fib = 0.900 Fic = 0.900 Fiv = 0.900

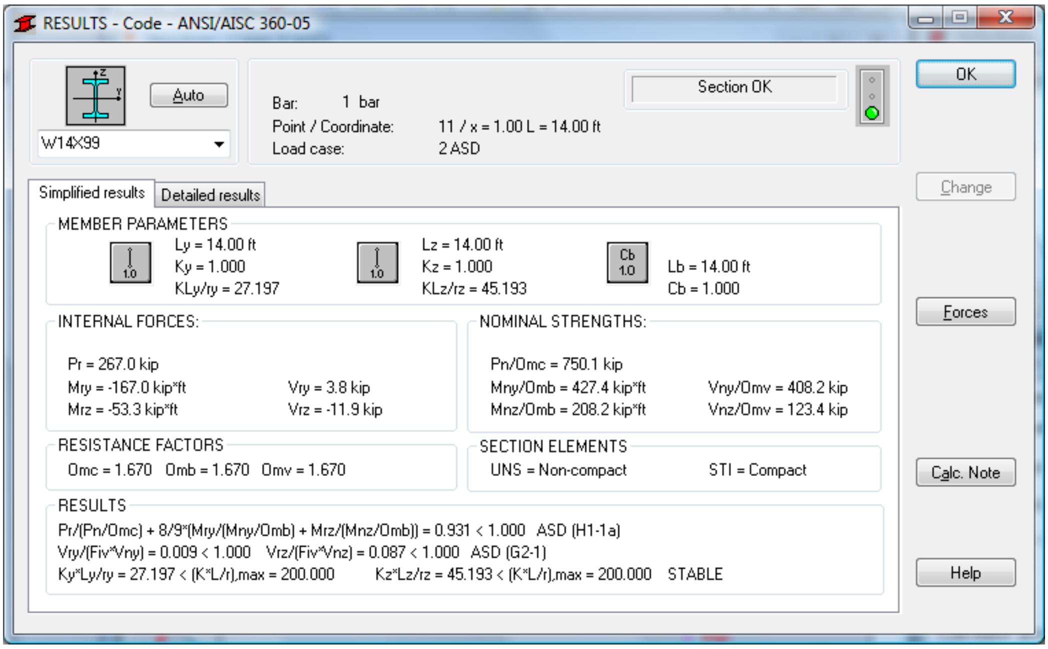
SECTION ELEMENTS:
UNS = Non-compact STI = Compact

VERIFICATION FORMULAS:
Pr/(Fic*Pn) + 8/9*(Mry/(Fib*Mny) + Mrz/(Fib*Mnz)) = 0.928 < 1.000 LRFD (H1-1a) Verified
Vry/(Fiv*Vny) = 0.009 < 1.000 LRFD (G2-1) Verified
Vrz/(Fiv*Vnz) = 0.087 < 1.000 LRFD (G2-1) Verified
Ky*Ly/ry = 27.197 < (K*L/r),max = 200.000 Kz*Lz/rz = 45.193 < (K*L/r),max = 200.000 STABLE

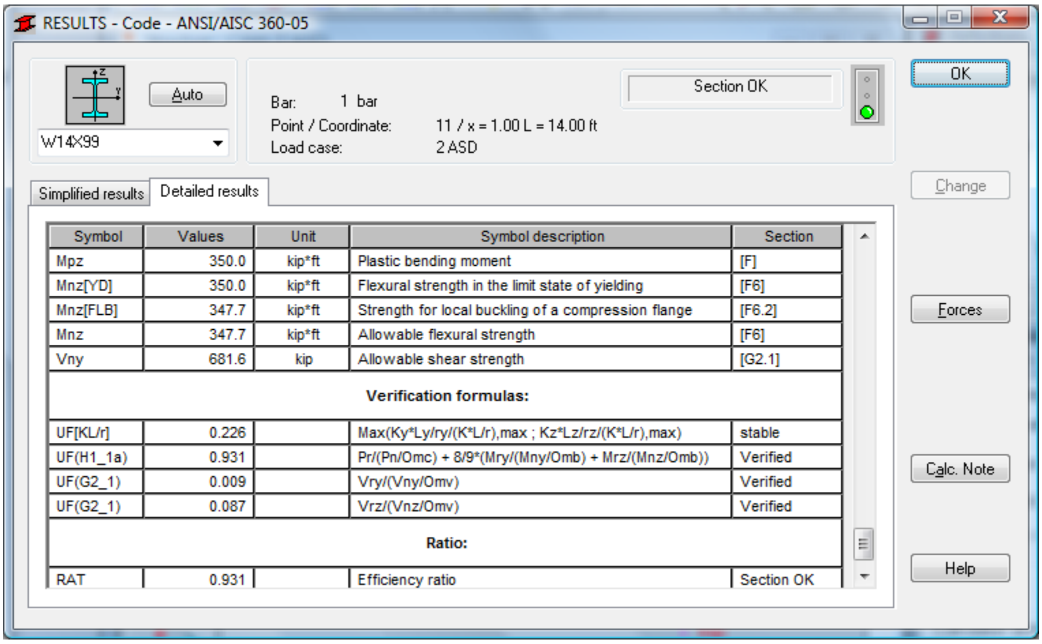
Section OK !!!

RESULTS for ASD method:

Simplified results tab



Detailed results tab



Pressing the *Calc.Note* button in “RESULTS –Code” dialog box opens the printout note for the analyzed member. You can obtain *Simplified results printout* or *Detailed results printout.*
It depends on which tab is active.
The printout note view of *Simplified results* for ASD is presented below.

STEEL DESIGN

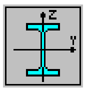
CODE: *ANSI/AISC 360-05 An American National Standard, March 9,2005*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 bar **POINT:** 11 **COORDINATE:** x = 1.00 L = 14.00 ft

---

LOADS:
Governing Load Case: 2 ASD

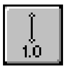
MATERIAL:
STEEL A992-50 Fy = 50.0 ksi Fu = 65.0 ksi E = 29000.0 ksi

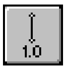


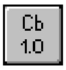
SECTION PARAMETERS: W14X99

d=14.16 in	Ay=22.721 in2	Az=6.868 in2	Ax=29.090 in2
b=14.57 in	Iy=1110.000 in4	Iz=402.000 in4	J=5.370 in4
tw=0.48 in	Sy=156.780 in3	Sz=55.201 in3	
tf=0.78 in	Zy=173.000 in3	Zz=84.000 in3	

MEMBER PARAMETERS:







Ly = 14.00 ft	Lz = 14.00 ft	
Ky = 1.000	Kz = 1.000	Lb = 14.00 ft
KLy/ry = 27.197	KLz/rz = 45.193	Cb = 1.000

INTERNAL FORCES:
Pr = 267.0 kip
Mry = -167.0 kip*ft Vry = 3.8 kip
Mrz = -53.3 kip*ft Vrz = -11.9 kip

NOMINAL STRENGTHS:
Pn/Omc = 750.1 kip
Mny/Omb = 427.4 kip*ft Vny/Omv = 408.2 kip
Mnz/Omb = 208.2 kip*ft Vnz/Omv = 123.4 kip

RESISTANCE FACTORS
Omb = 1.670 Omc = 1.670 Omv = 1.670

SECTION ELEMENTS:
UNS = Non-compact STI = Compact

VERIFICATION FORMULAS:
Pr/(Pn/Omc) + 8/9*(Mry/(Mny/Omb) + Mrz/(Mnz/Omb)) = 0.931 < 1.000 ASD (H1-1a) Verified
Vry/(Vny/Omv) = 0.009 < 1.000 ASD (G2-1) Verified
Vrz/(Vnz/Omv) = 0.087 < 1.000 ASD (G2-1) Verified
Ky*Ly/ry = 27.197 < (K*L/r),max = 200.000 Kz*Lz/rz = 45.193 < (K*L/r),max = 200.000 STABLE

Section OK !!!

COMPARISON:

verifications parameters, interaction expression	Robot	Handbook
LRFD Fib=0.90		
P_r - Required compressive strength [kips]	400	400
P_n - Design compressive strength [kips]	1252,7	1255,6
P_r < $Fic*P_n$	400< 1127,4	400< 1130
M_{ry} ; M_{rz} - Required flexural strength [kip*ft]	250 ; 80	250 ; 80
M_{ny} ; M_{nz} - Design compressive strength [kip*ft]	713,7 ; 347,7	713,3 ; 345,6
M_{ry} < Fib* M_{ny}	250 < 642,3	250 < 642
M_{rz} < Fib* M_{nz}	80 < 312,9	80 < 311
Pr / (Fic*Pn) > 0,2	0,355	0,354
Mry / (Fib*Mny)	0,389	0,389
Mrz / (Fib*Mnz)	0,256	0,257
Pr/(Fic*Pn) + 8/9*(Mry/(Fib*Mny) + Mrz/(Fib*Mnz)) = < 1.0 (H1-1a)	**0,928**	**0,928**
ASD Omc =1.67		
P_r - Required compressive strength [kips]	267	267
P_n - Design compressive strength [kips]	1252,7	1254,2
P_r < P_n/Omc	267 < 750,1	267 < 1254,2
M_{ry} ; M_{rz} - Required flexural strength [kip*ft]	167 ; 53,3	167 ; 53,3
M_{ny} ; M_{nz} - Design compressive strength [kip*ft]	713,7 ; 347,7	714,8 ; 345,7
M_{ry} < M_{ny} /Omc	167 < 427,4	167 < 428
M_{rz} < M_{nz} /Omc	53,3 < 208,2	53,3 < 207
Pr / (P_n/Omc) > 0,2	0,356	0,356
M_{ry} / (M_{ny} /Omc)	0,391	0,390
M_{rz} /(M_{nz} /Omc)	0,256	0,257
Pr/(Fic*Pn) + 8/9*(Mry/(Fib*Mny) + Mrz/(Fib*Mnz)) = < 1.0 (H1-1a)	**0,931**	**0,931**

CONCLUSIONS:
The small differences are caused by different accuracy of parameters in calculations.

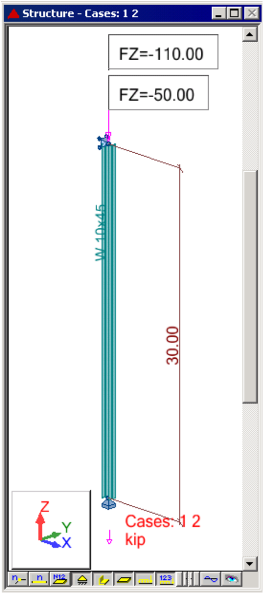
2. ASD 1989 ed. 9 th

VERIFICATION EXAMPLE 1
- Axially loaded columns

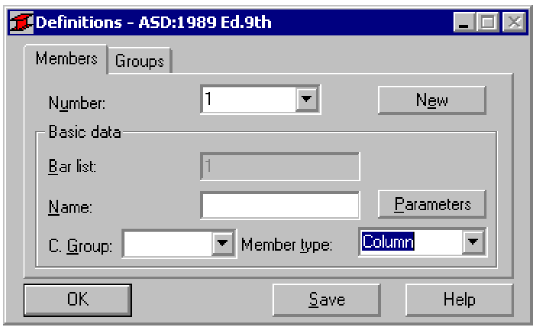
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

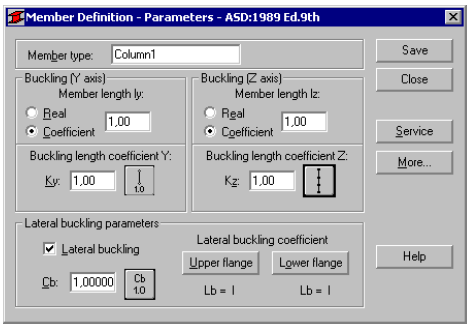
TITLE:
Axially loaded columns (Example 6.11.1)

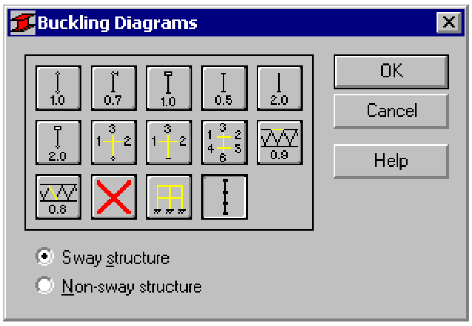
SPECIFICATION:
Select the lightest W section of A36 steel to serve as a main member 30 ft long to carry an axial compression load of 50 kips dead load and 110 kips live load in a braced structure, as shown aside. The member is assumed pinned at top and bottom and in addition has weak direction support at mid high. Use Allowable Stress Design.

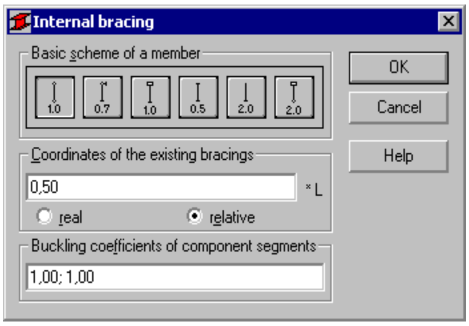


SOLUTION:
Define a new type of member. For analyzed member pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Column 1** in the *Member Type* editable field. Then, press *Buckling Length coefficient Z* icon and select the last icon. The new dialog box *Internal bracing* will appear. Define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. Save the newly-created type of member.

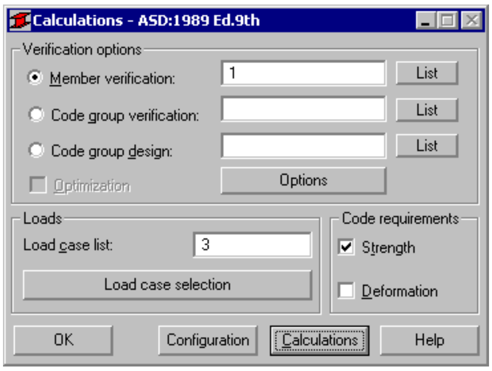




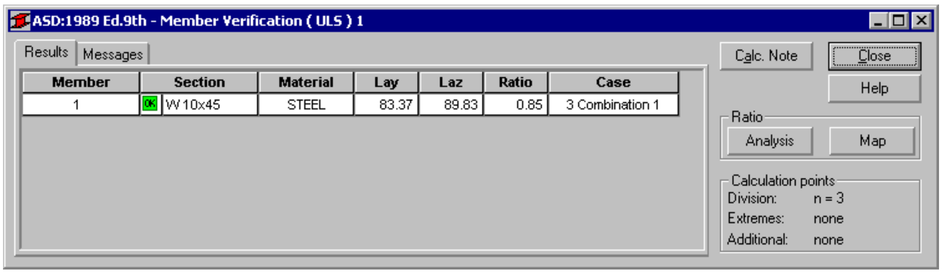




In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Code requirements – Deformation* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculation* button.



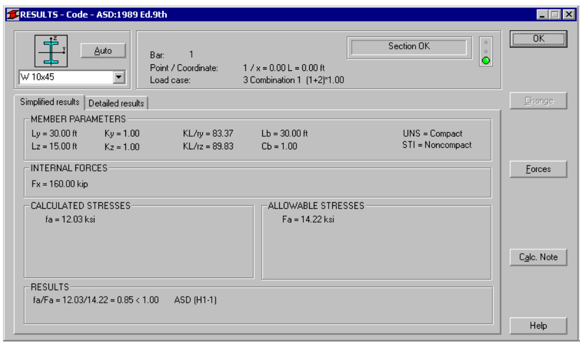
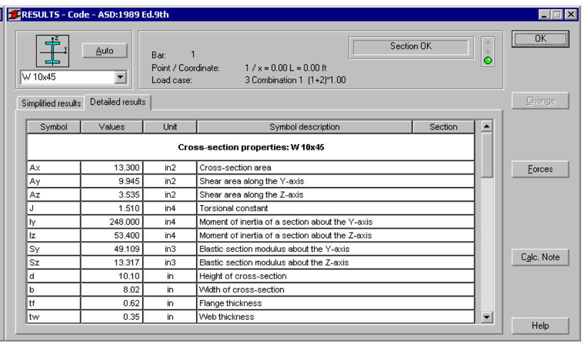
Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.

RESULTS:

a) In the first step W10x45 was considered. The results for the shape are presented below.

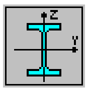
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 3 Combination 1 (1+2)*1.00

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 10x45

d=10.10 in			
b=8.02 in	Ay=9.945 in2	Az=3.535 in2	Ax=13.300 in2
tw=0.35 in	Iy=248.000 in4	Iz=53.400 in4	J=1.510 in4
tf=0.62 in	Wely=49.109 in3	Welz=13.317 in3	

MEMBER PARAMETERS:

Ly = 30.00 ft	Ky = 1.00	KL/ry = 83.37	Lb = 30.00 ft	UNS = Compact
Lz = 15.00 ft	Kz = 1.00	KL/rz = 89.83	Cb = 1.00	STI = Noncompact

---

INTERNAL FORCES:
Fx = 160.00 kip

CALCULATION STRESSES:	**ALLOWABLE STRESSES:**
fa = 12.03 ksi	Fa = 14.22 ksi

VERIFICATION FORMULAS:
fa/Fa = 12.03/14.22 = 0.85 < 1.00 ASD (H1-1)

Section OK !!!

b) From economical reason try to check the next lighter W section. Being still in *Detailed results* dialog box, type W 10x39 in the editable field below drawing of shape and press ENTER. The results for selected section are presented below.

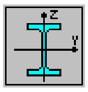
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 3 Combination 1 (1+2)*1.00

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 10x39

d=9.92 in			
b=7.99 in	Ay=8.464 in2	Az=3.125 in2	Ax=11.500 in2
tw=0.32 in	Iy=209.000 in4	Iz=45.000 in4	J=0.980 in4
tf=0.53 in	Wely=42.137 in3	Welz=11.271 in3	

MEMBER PARAMETERS:

Ly = 30.00 ft	Ky = 1.00	KL/ry = 84.45	Lb = 30.00 ft	UNS = Compact
Lz = 15.00 ft	Kz = 1.00	KL/rz = 90.99	Cb = 1.00	STI = Noncompact

---

INTERNAL FORCES:
Fx = 160.00 kip

CALCULATION STRESSES:
fa = 13.91 ksi

ALLOWABLE STRESSES:
Fa = 14.09 ksi

VERIFICATION FORMULAS:
fa/Fa = 13.91/14.09 = 0.99 < 1.00 ASD (H1-1)

Section OK !!!

COMPARISON:

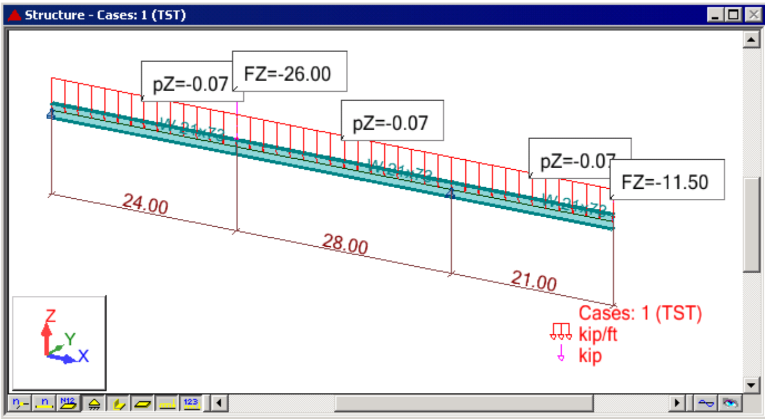
Resistance, interaction expression	Robot	Handbook
For W10x45 1. Service load compression stress $f_a = P/A_g$ [ksi] 2. Allowable stress at service load F_a [ksi]	 12.03 14.22	 12.0 14.3
For W10x39 1. Service load compression stress $f_a = P/A_g$ [ksi] 2. Allowable stress at service load F_a [ksi]	 13.91 14.09	 13.9 14.1

VERIFICATION EXAMPLE 2 - Lateral-torsional buckling of beams

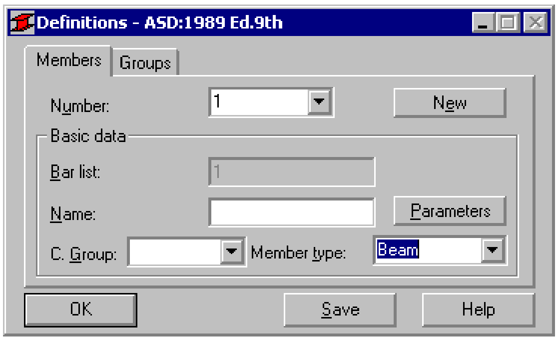
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

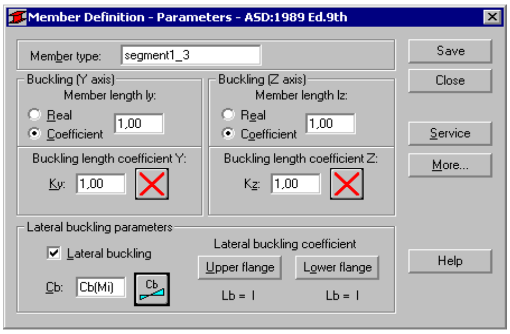
TITLE:
Lateral-torsional buckling of beams (Example 9.10.3).

SPECIFICATION:
Select an economical W section for the beam shown below. Lateral support is provided at the vertical supports, concentrated load points, and at the end of the cantilever. The 26-kip load (at point 2) contains 6 kips dead load and the 11.5-kip load (at point 4) includes 4 kips dead load: the remainder is live load. Use A36 steel and Allowable Steel Design.

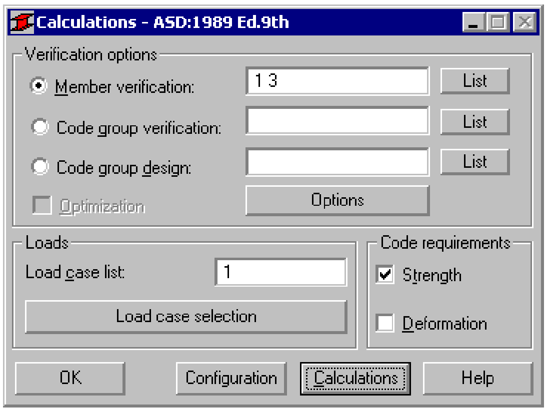


SOLUTION:
Define a new type of member 1. For analyzed member pre-defined type of member BEAM may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Segment 1_3** in the *Member Type* editable field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Save the newly-created type of member.
Assign previously defined label Segment 1_3 (type of member) to member 3.

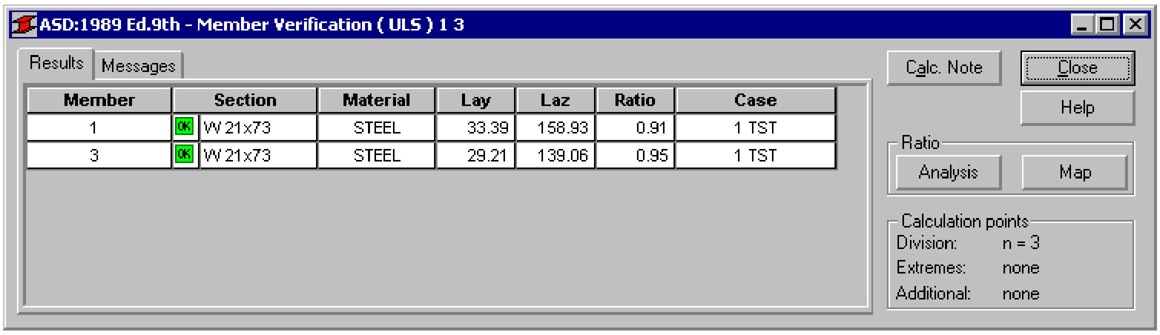




In the CALCULATIONS dialog box set *Member Verification* option for members 1 and 3 and switch off *Code requirements – Deformation* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button.

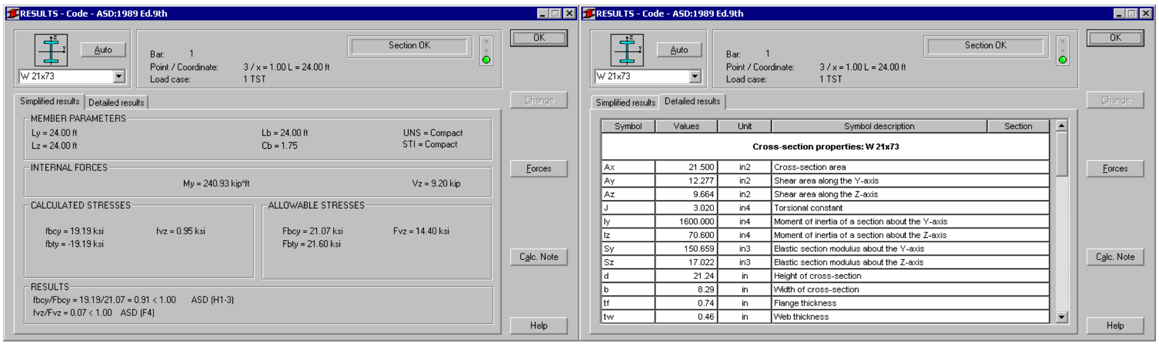


Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for member 1 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.



RESULTS:

a) for the first segment



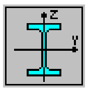
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 3 **COORDINATE:** x = 1.00 L = 24.00 ft

LOADS:
Governing Load Case: 1 TST

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 21x73

d=21.24 in
b=8.29 in Ay=12.277 in2 Az=9.664 in2 Ax=21.500 in2
tw=0.46 in Iy=1600.000 in4 Iz=70.600 in4 J=3.020 in4
tf=0.74 in Wely=150.659 in3 Welz=17.022 in3

MEMBER PARAMETERS:
Ly = 24.00 ft Lb = 24.00 ft UNS = Compact
Lz = 24.00 ft Cb = 1.75 STI = Compact

INTERNAL FORCES:
My = 240.93 kip*ft Vz = 9.20 kip

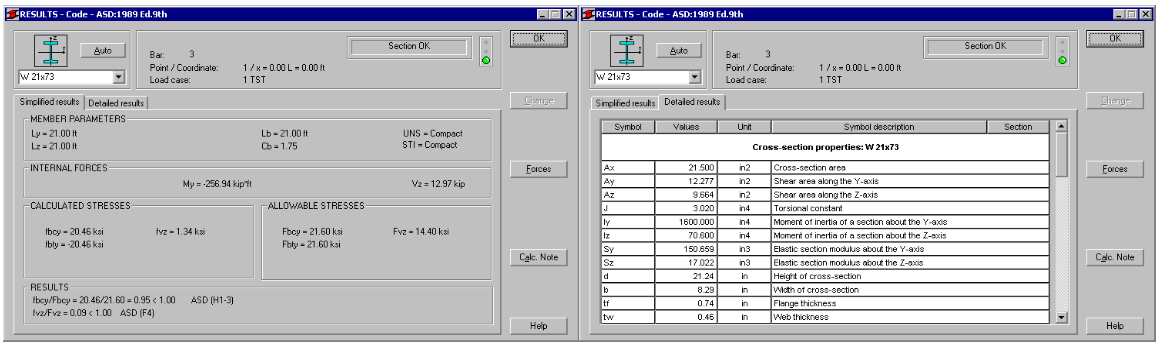
CALCULATION STRESSES: **ALLOWABLE STRESSES:**

fbcy = 19.19 ksi fvz = 0.95 ksi Fbcy = 21.07 ksi Fvz = 14.40 ksi
fbty = -19.19 ksi Fbty = 21.60 ksi

VERIFICATION FORMULAS:
fbcy/Fbcy = 19.19/21.07 = 0.91 < 1.00 ASD (H1-3)
fvz/Fvz = 0.07 < 1.00 ASD (F4)

Section OK !!!

b) for the third segment



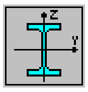
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 1 TST

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 21x73

d=21.24 in			
b=8.29 in	Ay=12.277 in2	Az=9.664 in2	Ax=21.500 in2
tw=0.46 in	Iy=1600.000 in4	Iz=70.600 in4	J=3.020 in4
tf=0.74 in	Wely=150.659 in3	Welz=17.022 in3	

MEMBER PARAMETERS:

Ly = 21.00 ft	Lb = 21.00 ft	UNS = Compact
Lz = 21.00 ft	Cb = 1.75	STI = Compact

INTERNAL FORCES:
My = -256.94 kip*ft Vz = 12.97 kip

CALCULATION STRESSES: **ALLOWABLE STRESSES:**

fbcy = 20.46 ksi	fvz = 1.34 ksi	Fbcy = 21.60 ksi	Fvz = 14.40 ksi
fbty = -20.46 ksi		Fbty = 21.60 ksi	

VERIFICATION FORMULAS:
fbcy/Fbcy = 20.46/21.60 = 0.95 < 1.00 ASD (H1-3)
fvz/Fvz = 0.09 < 1.00 ASD (F4)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
For the first segment 1. Service load flexural stress $f_{by} = P/A_g$ [ksi] 2. Allowable service load axial stress F_{bcz} [ksi]	 19.19 21.07	 19.1 21.1
For the first segment 1. Service load flexural stress $f_{by} = P/A_g$ [ksi] 2. Allowable service load axial stress F_{bcz} [ksi]	 20.46 21.6	 20.4 21.6

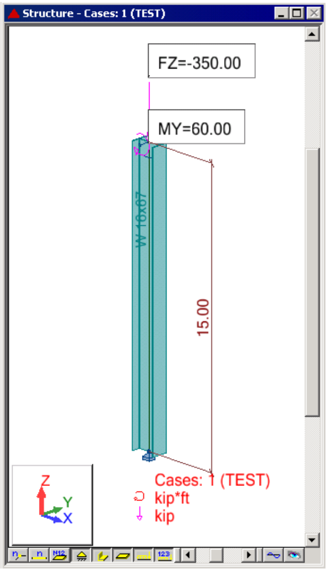
CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

VERIFICATION EXAMPLE 3
- Combined bending and axial load

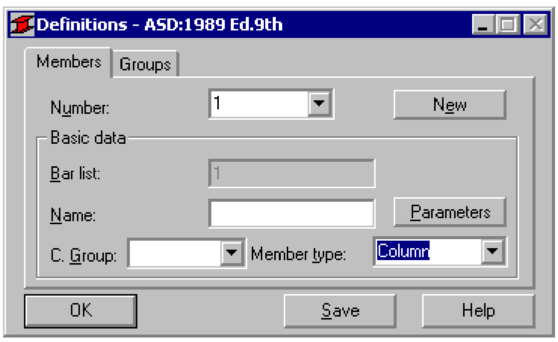
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

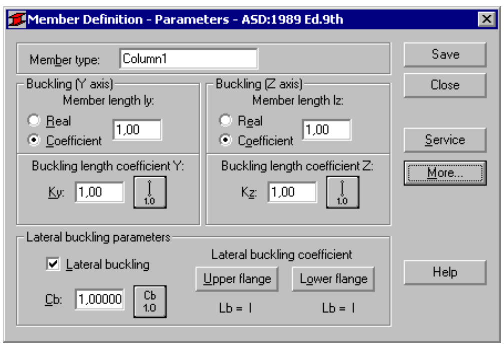
TITLE:
Combined bending and axial load (Example 12.14.1)

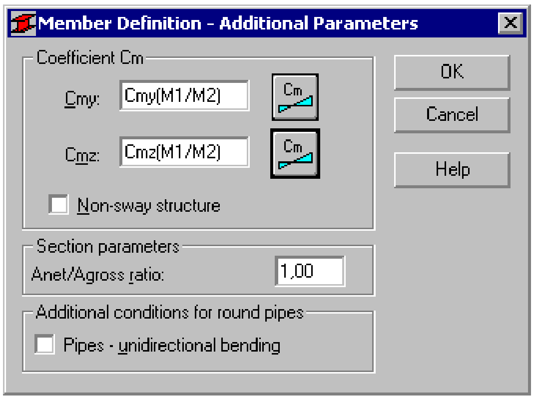
SPECIFICATION:
Investigate the acceptability of a W 16 x 67 used as a beam-column in a braced frame under the loading shown aside. The total service loads are P=350 kips and M=60 ft-kips. The steel is A572 Grade 60. Use Allowable Stress Design.

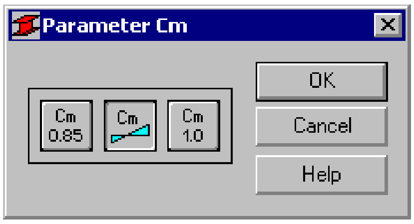


SOLUTION:
Define a new type of member. For analyzed member pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Column1** in the *Member Type* editable field. For defining appropriate values of Cm coefficients (coefficient applied to bending term in interaction equation), press *More* button. Choose the icon for Cmy and double-click the second icon (*Cmy calculated automatically*) in *Parameter Cm* dialog box. Repeat the same action for Cmz. Save the newly-created type of member.

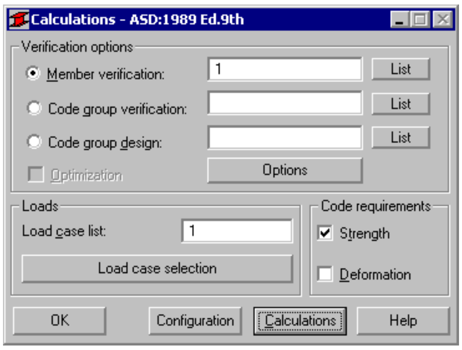




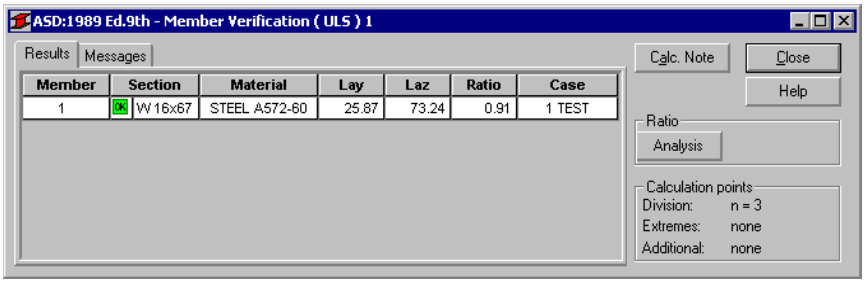




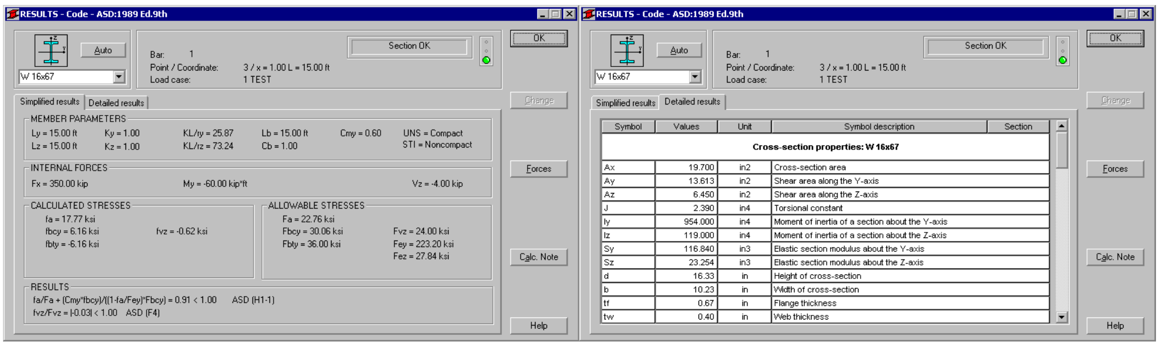
In the CALCULATIONS dialog box set *Member Verification* option for members 1 and switch off *Code requirements – Deformation* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button.



Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for member 1 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.



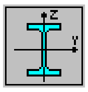
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 3 **COORDINATE:** x = 1.00 L = 15.00 ft

LOADS:
Governing Load Case: 1 TEST

MATERIAL:
STEEL A572-60 Fy = 60.00 ksi



SECTION PARAMETERS: W 16x67

d=16.33 in			
b=10.23 in	Ay=13.613 in2	Az=6.450 in2	Ax=19.700 in2
tw=0.40 in	Iy=954.000 in4	Iz=119.000 in4	J=2.390 in4
tf=0.67 in	Wely=116.840 in3	Welz=23.254 in3	

MEMBER PARAMETERS:

Ly = 15.00 ft	Ky = 1.00	KL/ry = 25.87	Lb = 15.00 ft	Cmy = 0.60	UNS = Compact
Lz = 15.00 ft	Kz = 1.00	KL/rz = 73.24	Cb = 1.00		STI = Noncompact

---

INTERNAL FORCES:
Fx = 350.00 kip My = -60.00 kip*ft Vz = -4.00 kip

CALCULATION STRESSES:		**ALLOWABLE STRESSES:**	
fa = 17.77 ksi		Fa = 22.76 ksi	
fbcy = 6.16 ksi	fvz = -0.62 ksi	Fbcy = 30.06 ksi	Fvz = 24.00 ksi
fbty = -6.16 ksi		Fbty = 36.00 ksi	Fey = 223.20 ksi
			Fez = 27.84 ksi

VERIFICATION FORMULAS:
fa/Fa + (Cmy*fbcy)/((1-fa/Fey)*Fbcy) = 0.91 < 1.00 ASD (H1-1)
fvz/Fvz = |-0.03| < 1.00 ASD (F4)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Allowable service load axial stress F_a [ksi]	17.77	17.8
2. Allowable bending stress at service load F_b [ksi]	30.06	29.9
3. Check ASD Formula (H1-1)	0.91	0.91

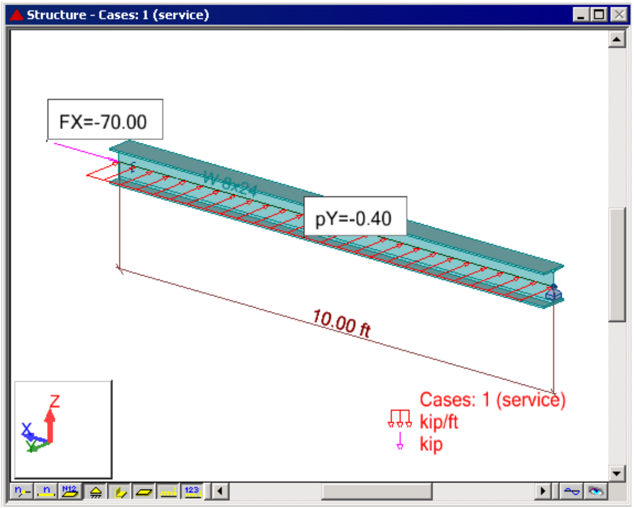
CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

VERIFICATION EXAMPLE 4
- Axial compression and bending about weak axis

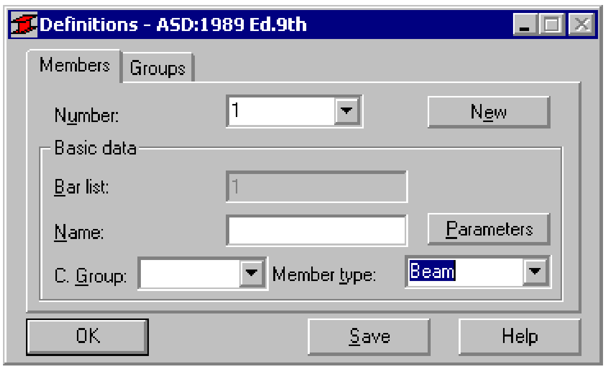
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

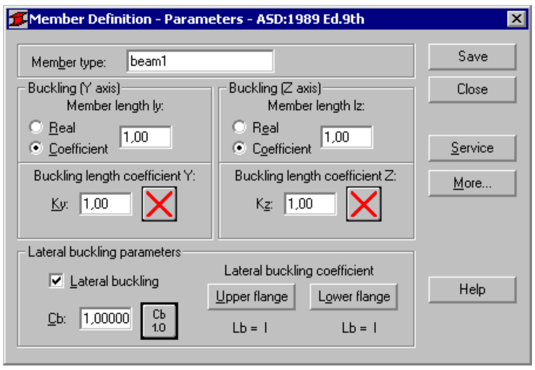
TITLE:
Axial compression and bending about weak axis (Example 12.15.3)

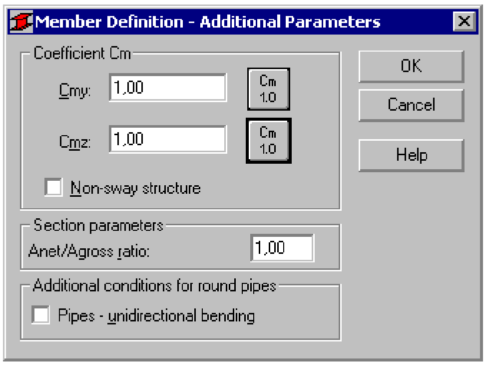
SPECIFICATION:
Investigate the adequacy according to Allowable Stress Design of the W8 x 24 sections shown aside. The member is loaded to cause bending about its weak axis and steel is A572 Grade.

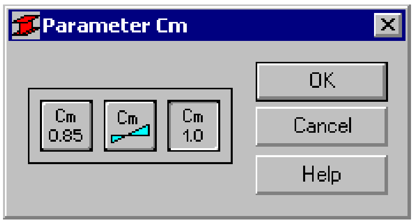


SOLUTION:
Define a new type of member. For analysed member pre-defined type of member BEAM may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Beam 1** in the *Member Type* editable field. For defining appropriate values of Cm coefficients (coefficient applied to bending term in interaction equation), press *More* button. Choose the icon for Cmy and double-click the third icon (*Cmy = 1.0*) in *Parameter Cm* dialog box. Repeat the same action for Cmz. Save the newly-created type of member.

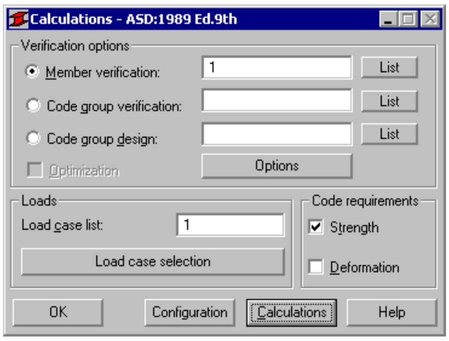




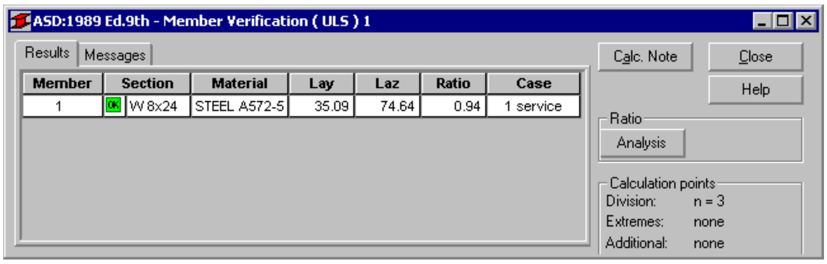




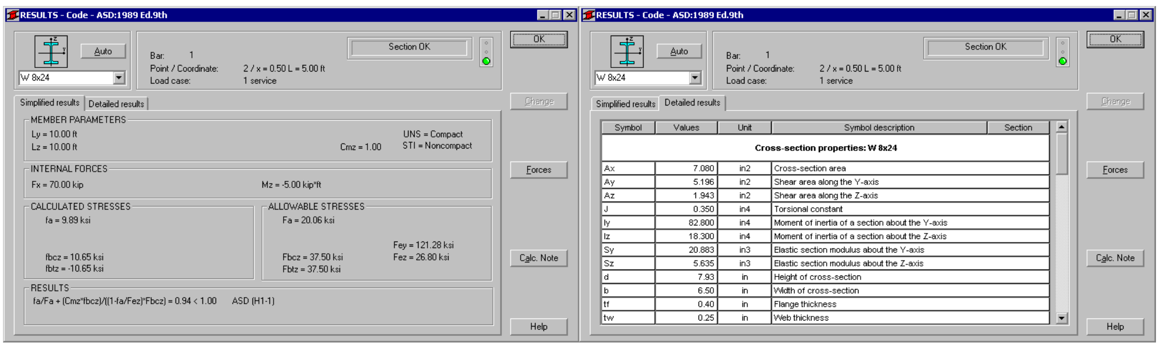
In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Code requirements – Deformation* (only Ultimate Limit state will be analysed). Now, start the calculations by pressing *Calculations* button.



Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for member 1 opens the RESULTS dialog box with detailed results for the analysed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.



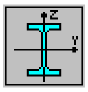
STEEL DESIGN

CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 2 **COORDINATE:** x = 0.50 L = 5.00 ft

LOADS:
Governing Load Case: 1 service

MATERIAL:
STEEL A572-50 Fy = 50.00 ksi



SECTION PARAMETERS: W 8x24

d=7.93 in			
b=6.50 in	Ay=5.196 in2	Az=1.943 in2	Ax=7.080 in2
tw=0.25 in	Iy=82.800 in4	Iz=18.300 in4	J=0.350 in4
tf=0.40 in	Wely=20.883 in3	Welz=5.635 in3	

MEMBER PARAMETERS:
Ly = 10.00 ft UNS = Compact
Lz = 10.00 ft Cmz = 1.00 STI = Noncompact

INTERNAL FORCES:
Fx = 70.00 kip Mz = -5.00 kip*ft

CALCULATION STRESSES:	ALLOWABLE STRESSES:	
fa = 9.89 ksi	Fa = 20.06 ksi	
		Fey = 121.28 ksi
fbcz = 10.65 ksi	Fbcz = 37.50 ksi	Fez = 26.80 ksi
fbtz = -10.65 ksi	Fbtz = 37.50 ksi	

VERIFICATION FORMULAS:
fa/Fa + (Cmz*fbcz)/((1-fa/Fez)*Fbcz) = 0.94 < 1.00 ASD (H1-1)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Allowable service load axial stress F_a [ksi]	20.06	20.1
2. Allowable bending stress at service load F_{bcz} [ksi]	37.5	37.5
3. Check ASD Formula (H1-1)	0.94	0.95

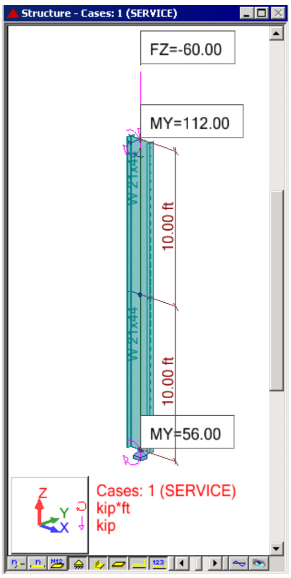
CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

VERIFICATION EXAMPLE 5
- Frame member under axial compression / bending

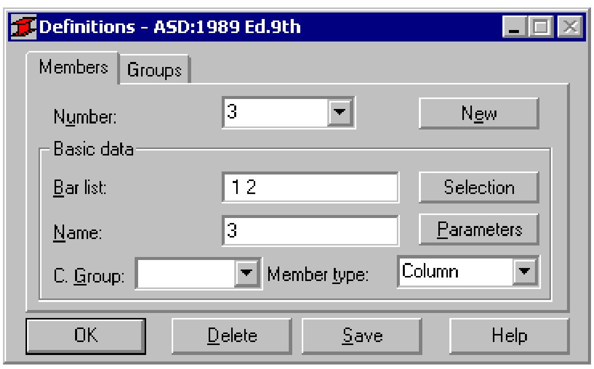
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

TITLE:
Frame member under axial compression and bending (Example 12.15.4).

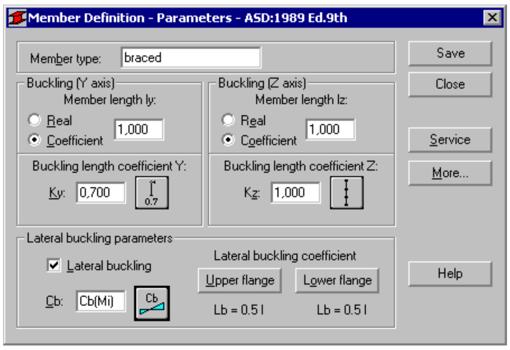
SPECIFICATION:
Select a suitable W section for the column member of the frame, using service loads P=60 kips and M=112 ft-kips. The joints are rigid to give frame action in the plane of bending, but in the transverse direction sway bracing is provided and the attachments may be considered hinged. Use A36 steel and Allowable Stress Design.
Solve for the following two cases:
1. Braced frame in the plane of bending.
2. Unbraced frame in the plane of bending.

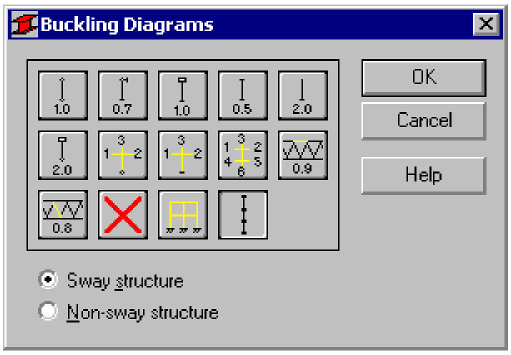


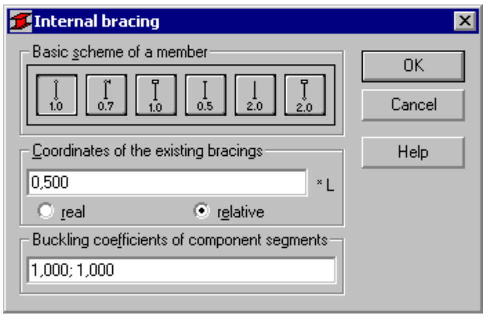
SOLUTION:
Create a new super-member No.3 consists two bars (1 and 2) by pressing *New* button in *Definition – ASD* dialog-box. Type 1 2 in Bar List editable field. Then, define a new type of member. For member 3 analyzed as a member of braced frame pre-defined type of member COLUMN may be initially opened. It can be set in *Member Type* combo-box.

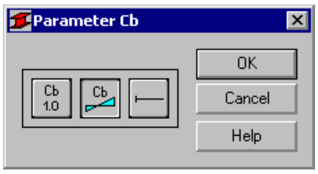


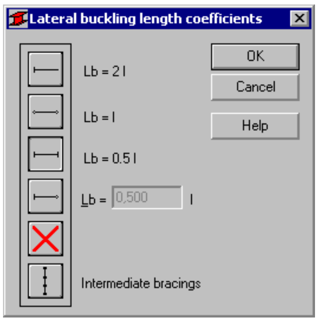
Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Braced** in the *Member Type* editable field. Then press *Buckling Length coefficient Y* icon and select the second icon (Ky = 0.7). Next, press *Buckling Length coefficient Z* icon and select the last icon. The new dialog box *Internal bracing* will appear. Define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Next, press the *Upper flange* button that opens *Lateral buckling length coefficients* dialog box and choose the icon Lb=0.5L. Repeat the same action for *Lower flange*.



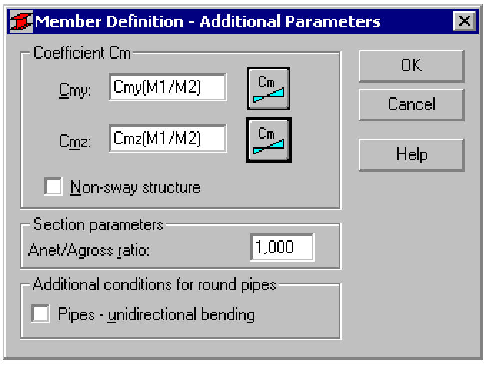


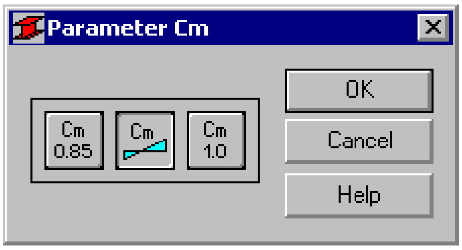




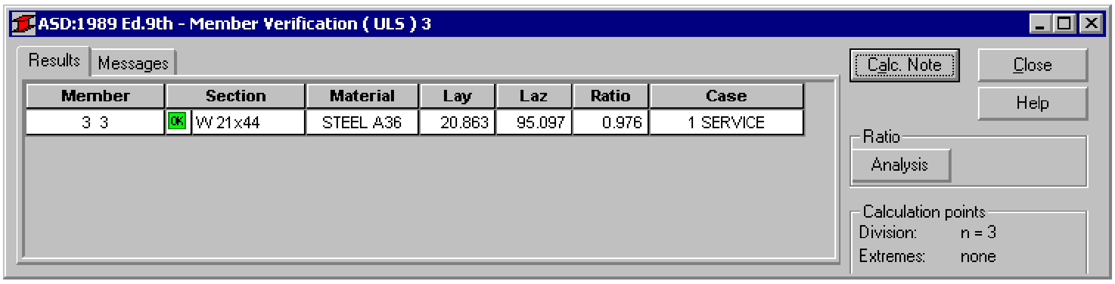


For defining appropriate values of Cm coefficients (coefficient applied to bending term in interaction equation), press *More* button. Choose the icon for Cmy and double-click the second icon (*Cmy calculated automatically*) in *Parameter Cm* dialog box. Repeat the same action for Cmz. Save the newly-created type of member.



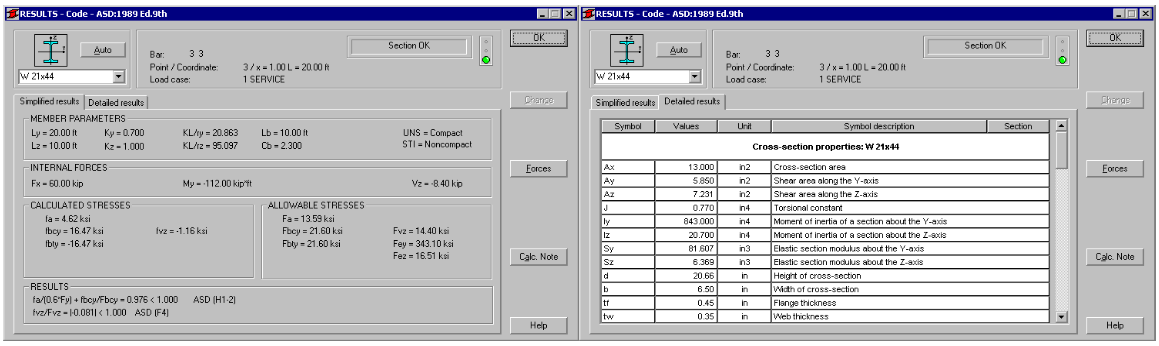


In the CALCULATIONS dialog box set *Member Verification* option for member 3 and switch off *Code requirements – Deformation* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button. Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for member 3 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.

1. W21x44 for the braced frame



STEEL DESIGN

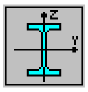
CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 3 **POINT:** 3 **COORDINATE:** x = 1.00 L = 20.00 ft

---

LOADS:
Governing Load Case: 1 SERVICE

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 21x44

d=20.66 in			
b=6.50 in	Ay=5.850 in2	Az=7.231 in2	Ax=13.000 in2
tw=0.35 in	Iy=843.000 in4	Iz=20.700 in4	J=0.770 in4
tf=0.45 in	Wely=81.607 in3	Welz=6.369 in3	

MEMBER PARAMETERS:

Ly = 20.00 ft	Ky = 0.700	KL/ry = 20.863	Lb = 10.00 ft	UNS = Compact
Lz = 10.00 ft	Kz = 1.000	KL/rz = 95.097	Cb = 2.300	STI = Noncompact

---

INTERNAL FORCES:
Fx = 60.00 kip My = -112.00 kip*ft Vz = -8.40 kip

CALCULATION STRESSES:

fa = 4.62 ksi

fbcy = 16.47 ksi   fvz = -1.16 ksi

fbty = -16.47 ksi

ALLOWABLE STRESSES:

Fa = 13.59 ksi

Fbcy = 21.60 ksi   Fvz = 14.40 ksi

Fbty = 21.60 ksi   Fey = 343.10 ksi

Fez = 16.51 ksi

VERIFICATION FORMULAS:

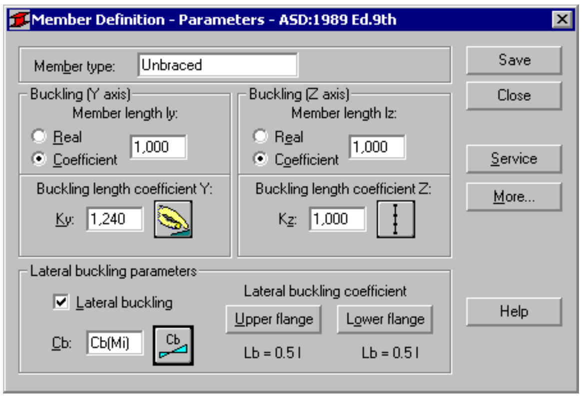
fa/(0.6*Fy) + fbcy/Fbcy = 0.976 < 1.000   ASD (H1-2)

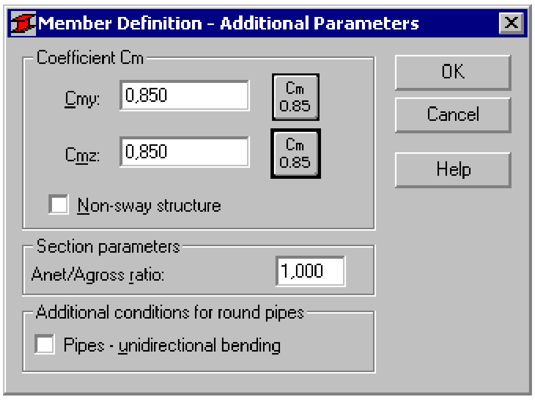
fvz/Fvz = |-0.081| < 1.000   ASD (F4)

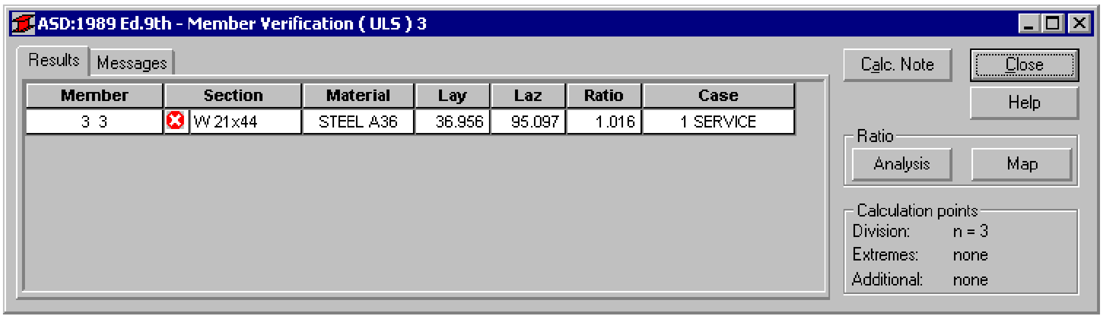
Section OK !!!

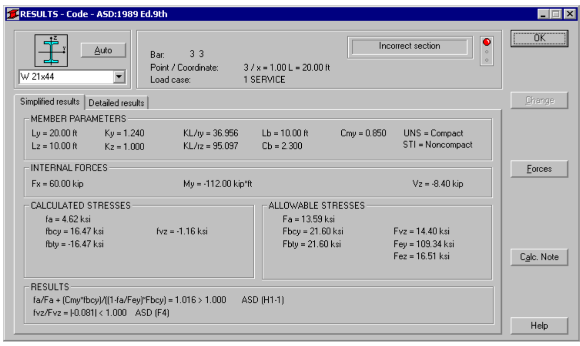
2. W21x44 for the unbraced frame

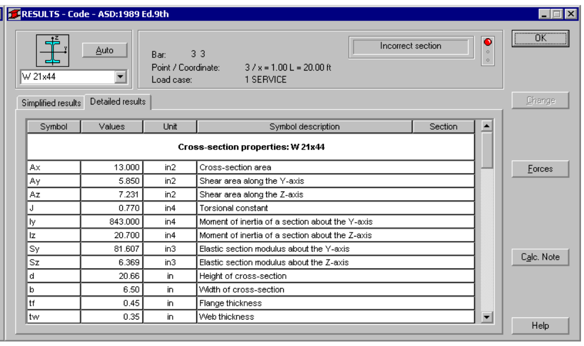
Using previously defined member type *Braced* create the new set of parameters for unbraced frame. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Unbraced** in the *Member Type* editable field. Define the new value of *Buckling Length coefficient Y* by typing value 1.24 in editable field. For defining appropriate values of Cm coefficients (coefficient applied to bending term in interaction equation), press *More* button. Choose the icon for Cmy and double-click the first icon (*Cmy =0.85*) in *Parameter Cm* dialog box. Repeat the same action for Cmz. Save the newly-created type of member. Make the calculations for member 3.











STEEL DESIGN

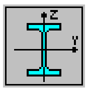
CODE: *Allowable Stress Design - Ninth Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 3 **POINT:** 3 **COORDINATE:** x = 1.00 L = 20.00 ft

---

LOADS:
Governing Load Case: 1 SERVICE

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 21x44

d=20.66 in			
b=6.50 in	Ay=5.850 in2	Az=7.231 in2	Ax=13.000 in2
tw=0.35 in	Iy=843.000 in4	Iz=20.700 in4	J=0.770 in4
tf=0.45 in	Wely=81.607 in3	Welz=6.369 in3	

MEMBER PARAMETERS:

Ly = 20.00 ft	Ky = 1.240	KL/ry = 36.956	Lb = 10.00 ft	Cmy = 0.850	UNS = Compact
Lz = 10.00 ft	Kz = 1.000	KL/rz = 95.097	Cb = 2.300		STI = Noncompact

---

INTERNAL FORCES:
Fx = 60.00 kip My = -112.00 kip*ft Vz = -8.40 kip

CALCULATION STRESSES:
fa = 4.62 ksi
fbcy = 16.47 ksi fvz = -1.16 ksi
fbty = -16.47 ksi

ALLOWABLE STRESSES:
Fa = 13.59 ksi Fvz = 14.40 ksi
Fbcy = 21.60 ksi Fey = 109.34 ksi
Fbty = 21.60 ksi Fez = 16.51 ksi

VERIFICATION FORMULAS:
fa/Fa + (Cmy*fbcy)/((1-fa/Fey)*Fbcy) = 1.016 > 1.000 ASD (H1-1)
fvz/Fvz = |-0.081| < 1.000 ASD (F4)

Incorrect section !!!

For this unbraced frame the stability requirement governs. Thus if a small overstress is acceptable for the unbraced frame, the same W21x44 could be used whether the frame is braced or unbraced.

COMPARISON:

Resistance, interaction expression	Robot	Handbook
W21x44 in braced frame		
1. Allowable service load axial stress F_a [ksi]	13.59	13.6
2. Allowable bending stress at service load F_{bcy} [ksi]	21.6	21.4
3. Check ASD Formula (H1-1)	0.976	0.98
W21x44 in unbraced frame		
4. Allowable service load axial stress F_a [ksi]	13.59	13.6
5. Allowable bending stress at service load F_{bcy} [ksi]	21.6	21.4
6. Check ASD Formula (H1-1)	1.016	1.03

CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

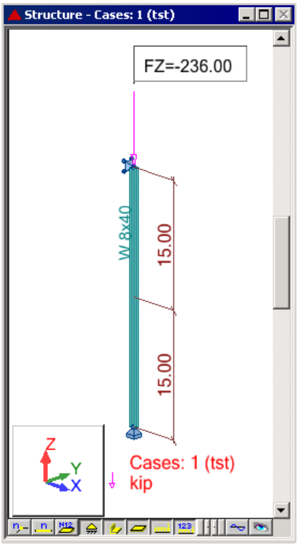
3. LRFD

VERIFICATION EXAMPLE 1
- Axially loaded column

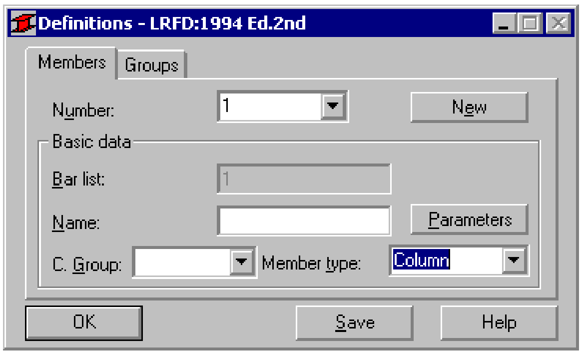
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

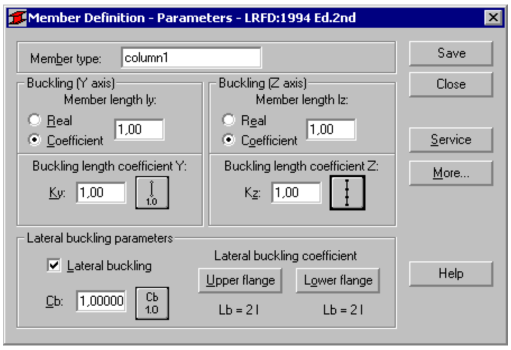
TITLE:
Axially loaded column (Example 6.10.2)

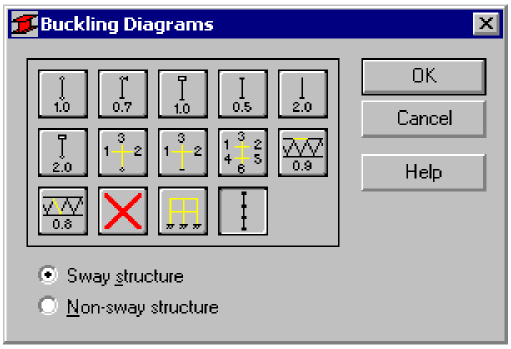
SPECIFICATION:
Select the lightest W section of A36 steel to serve as a main member 30 ft long to carry an axial compression load of 50 kips dead load and 110 kips live load in a braced structure, as shown below. The member is assumed pinned at top and bottom and in addition has weak direction support at mid-height. Use AISC Load and Resistance Factor Design.

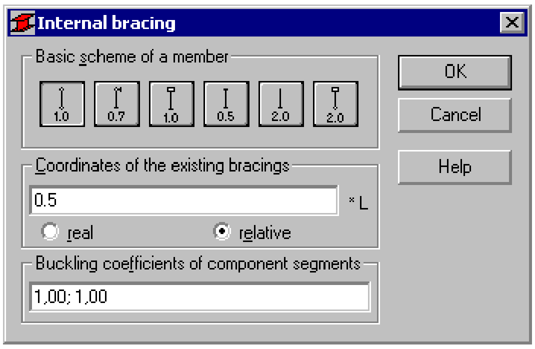


SOLUTION:
Define a new type of member. For analyzed member pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Column 1** in the *Member Type* editable field. Then, press *Buckling Length coefficient Z* icon and select the last icon. The new dialog box *Internal bracing* will appear. Define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. Save the newly-created type of member.

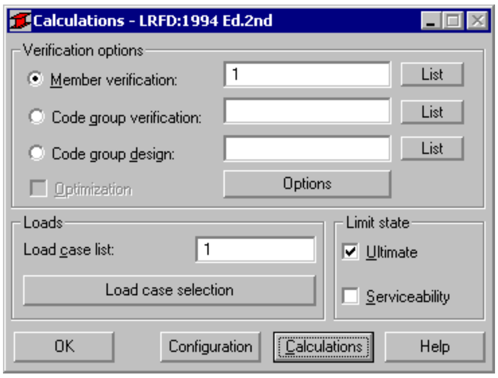








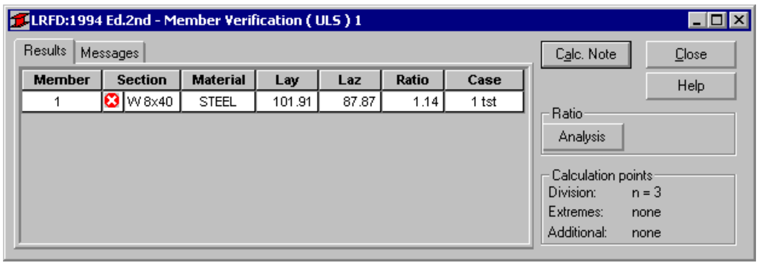
In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button.

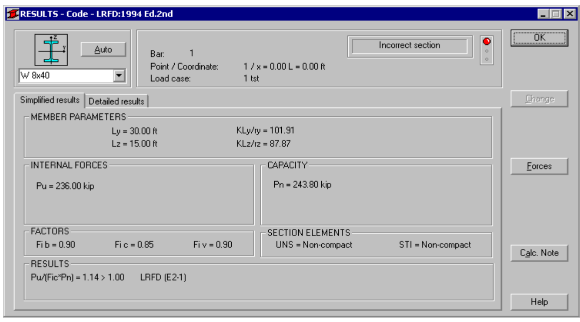


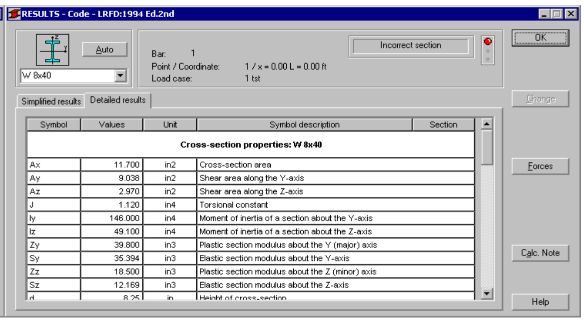
Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.

RESULTS:

a) In the first step W8x40 was considered. The results for the shape are presented below.







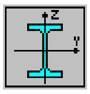
STEEL DESIGN

CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 1 tst

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 8x40

d=8.25 in	Ay=9.038 in2	Az=2.970 in2	Ax=11.700 in2
b=8.07 in	Iy=146.000 in4	Iz=49.100 in4	J=1.120 in4
tw=0.36 in	Sy=35.394 in3	Sz=12.169 in3	
tf=0.56 in	Zy=39.800 in3	Zz=18.500 in3	

MEMBER PARAMETERS:
Ly = 30.00 ft KLy/ry = 101.91
Lz = 15.00 ft KLz/rz = 87.87

INTERNAL FORCES:
Pu = 236.00 kip

NOMINAL STRENGTHS:
Pn = 243.80 kip

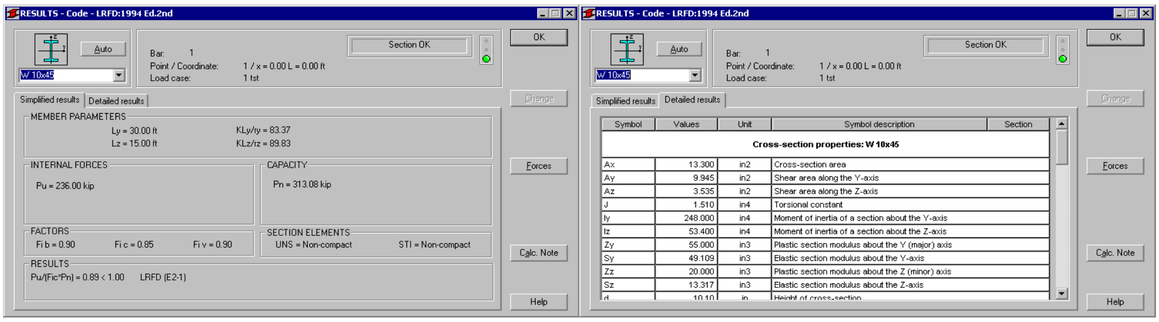
COEFFICIENTS:
Fi b = 0.90 Fi c = 0.85 Fi v = 0.90

SECTION ELEMENTS:
UNS = Non-compact STI = Non-compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) = 1.14 > 1.00 LRFD (E2-1)

Incorrect section !!!

b) Now check W10x45. Being still in *Detailed results* dialog box, type W 10x45 in the editable field below drawing of shape and press ENTER. The results for selected section are presented below.



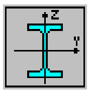
STEEL DESIGN

CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 1 tst

MATERIAL:
STEEL Fy = 36.00 ksi



SECTION PARAMETERS: W 10x45

d=10.10 in	Ay=9.945 in2	Az=3.535 in2	Ax=13.300 in2
b=8.02 in	Iy=248.000 in4	Iz=53.400 in4	J=1.510 in4
tw=0.35 in	Sy=49.109 in3	Sz=13.317 in3	
tf=0.62 in	Zy=54.900 in3	Zz=20.300 in3	

MEMBER PARAMETERS:
Ly = 30.00 ft KLy/ry = 83.37
Lz = 15.00 ft KLz/rz = 89.83

INTERNAL FORCES:
Pu = 236.00 kip

NOMINAL STRENGTHS:
Pn = 313.08 kip

COEFFICIENTS:
Fi b = 0.90 Fi c = 0.85 Fi v = 0.90

SECTION ELEMENTS:
UNS = Non-compact STI = Non-compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) = 0.89 < 1.00 LRFD (E2-1)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Compressive resistance $\phi_c P_n$ [kips] for W8x40	207.23	208
2. Compressive resistance $\phi_c P_n$ [kips] for W10x45	266.12	267

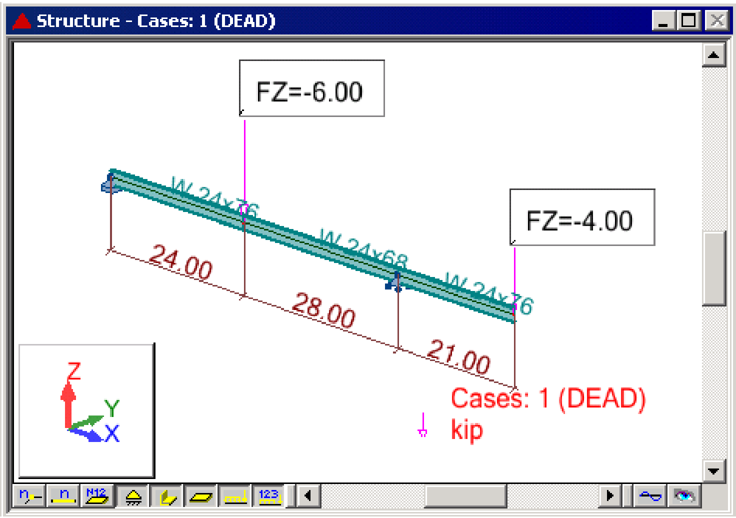
CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

VERIFICATION EXAMPLE 2 - Lateral torsional buckling of beams

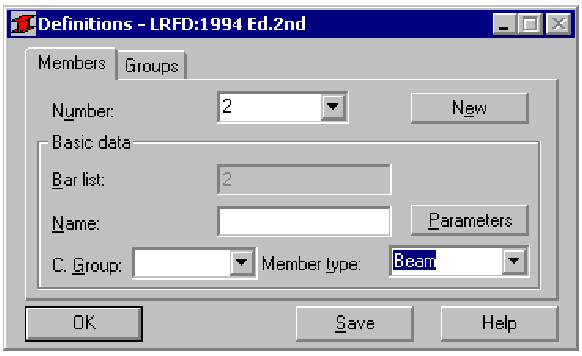
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

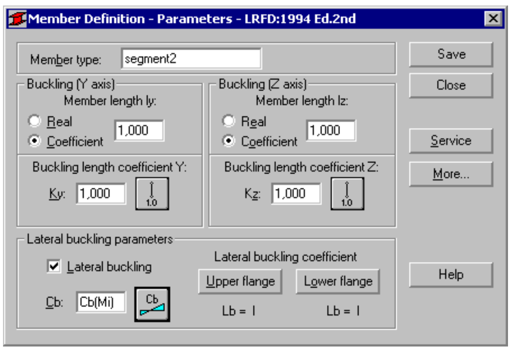
TITLE:
Lateral-torsional buckling of beams (Example 9.9.3).

SPECIFICATION:
Select an economical W section for the beam as shown below. Lateral support is provided at the vertical supports, concentrated load points, and at the end of the cantilever. The 26-kip load (at point 2) contains 6 kips dead load and the 11.5-kip load (at point 4) includes 4 kips dead load: the remainder is live load. Use A36 steel and Load and Resistance Factor Design.

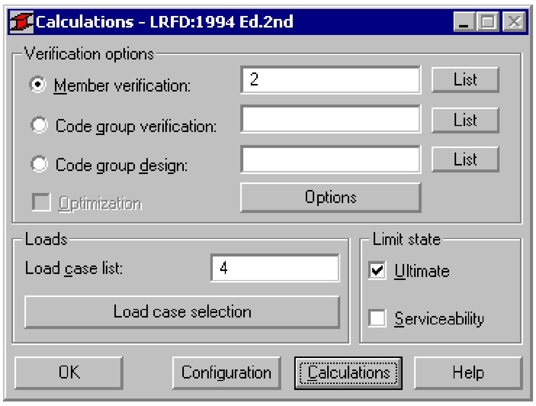


Define a new type of member 2. For analyzed member pre-defined type of member BEAM may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Segment 2** in the *Member Type* editable field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Save the newly-created type of member. Assign previously defined label Segment 2 (type of member) to member 2.





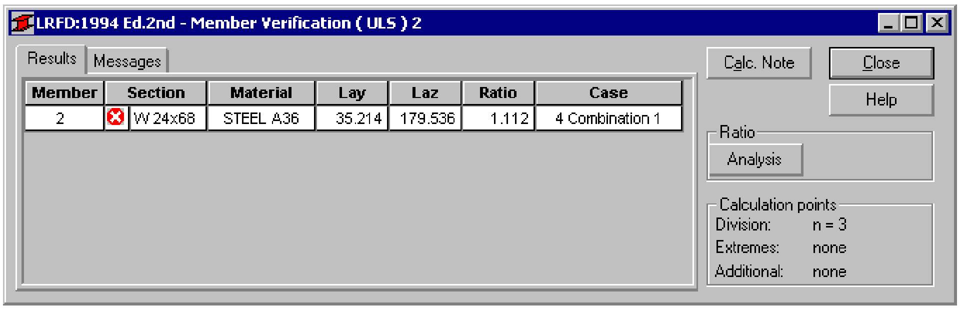
In the CALCULATIONS dialog box set *Member Verification* option for members 2 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button.

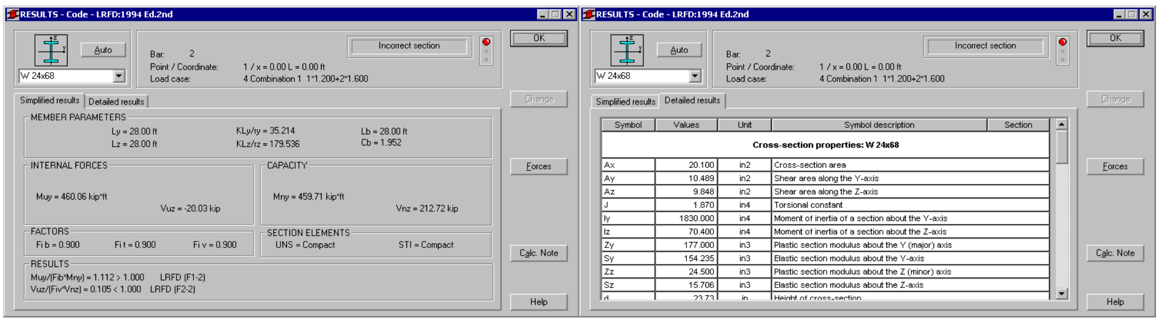


Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 2 opens the RESULTS dialog box with detailed results for the analyzed member. The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.

RESULTS:

a) In the first step W 24x68 was considered





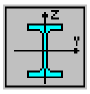
STEEL DESIGN

CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 2 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 4 Combination 1 1*1.200+2*1.600

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 24x68

d=23.73 in	Ay=10.489 in2	Az=9.848 in2	Ax=20.100 in2
b=8.96 in	Iy=1830.000 in4	Iz=70.400 in4	J=1.870 in4
tw=0.41 in	Sy=154.235 in3	Sz=15.706 in3	
tf=0.58 in	Zy=177.000 in3	Zz=24.500 in3	

MEMBER PARAMETERS:

Ly = 28.00 ft	KLy/ry = 35.214	Lb = 28.00 ft
Lz = 28.00 ft	KLz/rz = 179.536	Cb = 1.952

INTERNAL FORCES: **NOMINAL STRENGTHS:**

Muy = 460.06 kip*ft Vuz = -20.03 kip Mny = 459.71 kip*ft Vnz = 212.72 kip

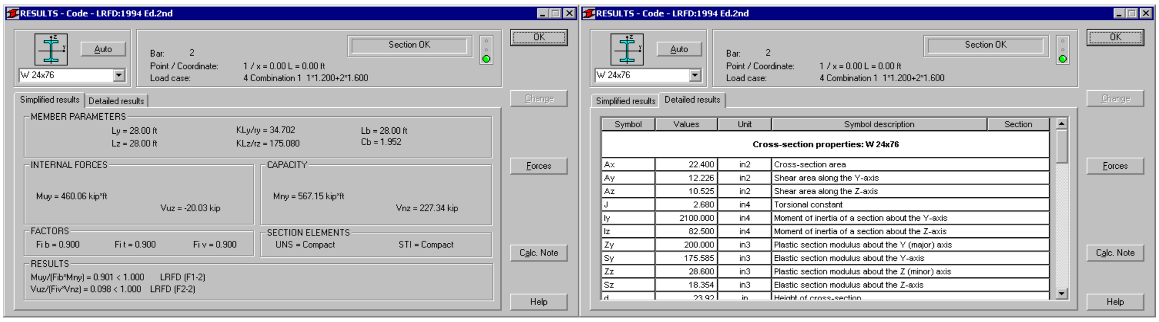
COEFFICIENTS:
Fi b = 0.900 Fi t = 0.900 Fi v = 0.900

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Muy/(Fib*Mny) = 1.112 > 1.000 LRFD (F1-2)
Vuz/(Fiv*Vnz) = 0.105 < 1.000 LRFD (F2-2)

Incorrect section !!!

b) Now check W24x76. Being still in *Detailed results* dialog box, type W 24x76 in the editable field below drawing of shape and press ENTER. The results for selected section are presented below.



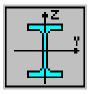
STEEL DESIGN

CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 2 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 ft

LOADS:
Governing Load Case: 4 Combination 1 1*1.200+2*1.600

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 24x76

d=23.92 in	Ay=12.226 in2	Az=10.525 in2	Ax=22.400 in2
b=8.99 in	Iy=2100.000 in4	Iz=82.500 in4	J=2.680 in4
tw=0.44 in	Sy=175.585 in3	Sz=18.354 in3	
tf=0.68 in	Zy=200.000 in3	Zz=28.600 in3	

MEMBER PARAMETERS:

Ly = 28.00 ft	KLy/ry = 34.702	Lb = 28.00 ft
Lz = 28.00 ft	KLz/rz = 175.080	Cb = 1.952

INTERNAL FORCES: **NOMINAL STRENGTHS:**

Muy = 460.06 kip*ft Vuz = -20.03 kip Mny = 567.15 kip*ft Vnz = 227.34 kip

---

COEFFICIENTS:
Fi b = 0.900 Fi t = 0.900 Fi v = 0.900

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Muy/(Fib*Mny) = 0.901 < 1.000 LRFD (F1-2)
Vuz/(Fiv*Vnz) = 0.098 < 1.000 LRFD (F2-2)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Nominal moment strength Mny [ft-kips] for W24x68	459,71	468
2. Nominal moment strength Mny [ft-kips] for W24x73	567,15	581

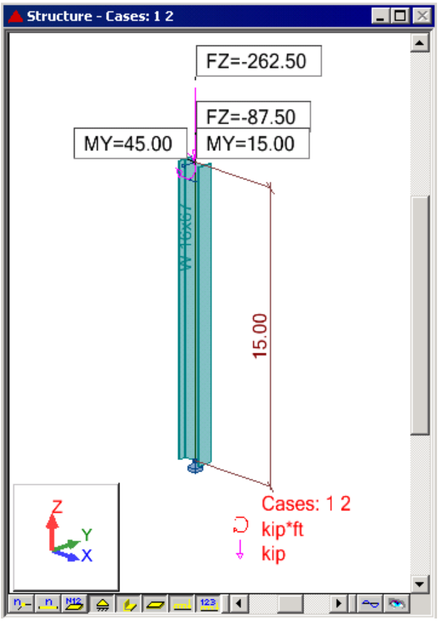
CONCLUSIONS:
The differences are caused by different way of Cb calculations in the handbook and in the program. Robot uses the new equation given by LRFD Second edition in chapter F formula (F1-3). In Handbook the old equation was used.

VERIFICATION EXAMPLE 3
- Combined bending and axial compression

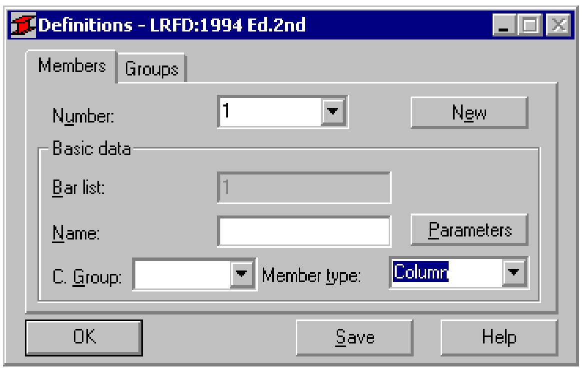
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

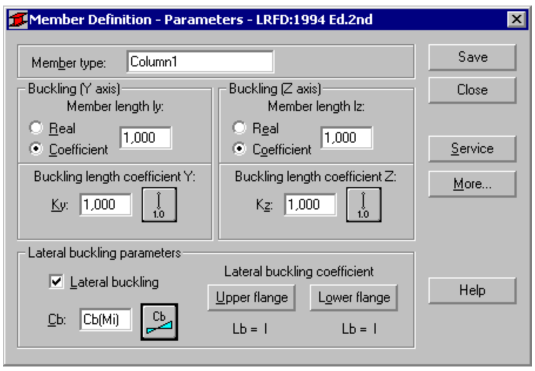
TITLE:
Combined bending and axial compression (Example 12.10.1).

SPECIFICATION:
Investigate the acceptability of a W 16 x 67 used as a beam-column in a braced frame under the loading shown aside. The steel is A572 Grade 60.Use Load and Design Factor Design.

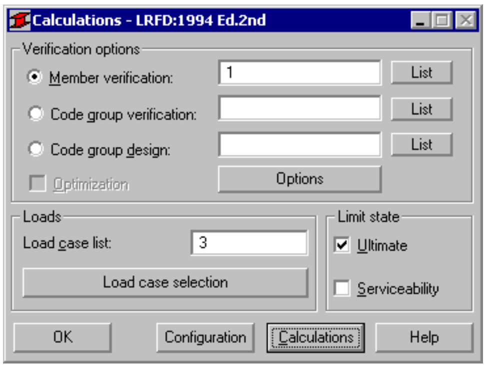


SOLUTION:
Define a new type of member. For analyzed member pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button in DEFINITION-MEMBERS tab, which opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Column1** in the *Member Type* editable field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Save the newly-created type of member.

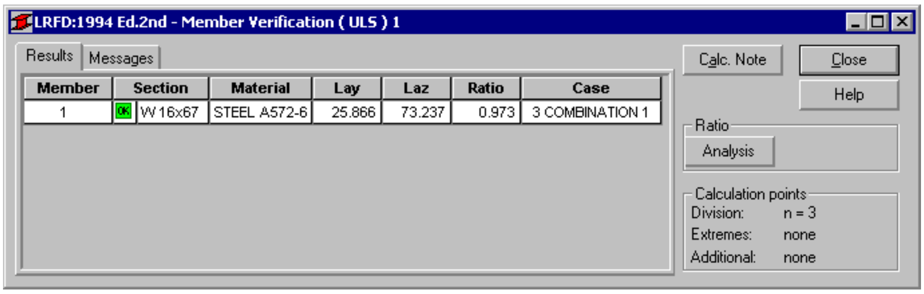




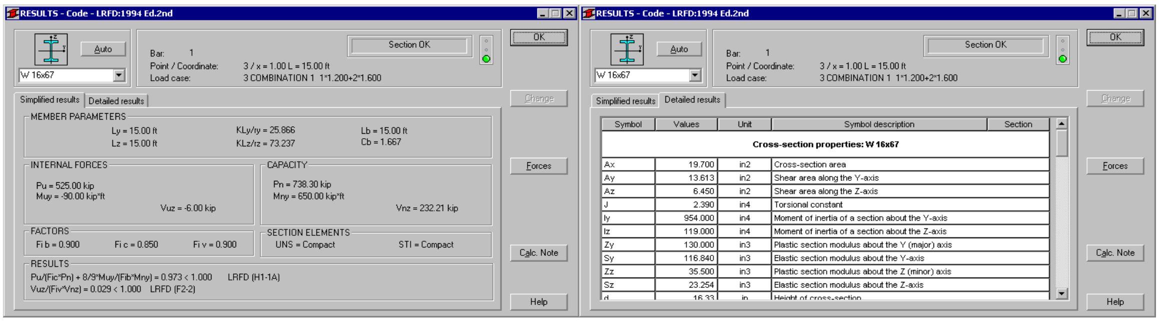
In the CALCULATIONS dialog box set *Member Verification* option for members 1 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button.



Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 1 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.



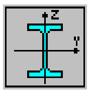
STEEL DESIGN

CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 3 **COORDINATE:** x = 1.00 L = 15.00 ft

LOADS:
Governing Load Case: 3 COMBINATION 1 1*1.200+2*1.600

MATERIAL:
STEEL A572-60 Fy = 60.00 ksi



SECTION PARAMETERS: W 16x67

d=16.33 in	Ay=13.613 in2	Az=6.450 in2	Ax=19.700 in2
b=10.23 in	Iy=954.000 in4	Iz=119.000 in4	J=2.390 in4
tw=0.40 in	Sy=116.840 in3	Sz=23.254 in3	
tf=0.67 in	Zy=130.000 in3	Zz=35.500 in3	

MEMBER PARAMETERS:

Ly = 15.00 ft	KLy/ry = 25.866	Lb = 15.00 ft
Lz = 15.00 ft	KLz/rz = 73.237	Cb = 1.667

INTERNAL FORCES:
Pu = 525.00 kip
Muy = -90.00 kip*ft Vuz = -6.00 kip

NOMINAL STRENGTHS:
Pn = 738.30 kip
Mny = 650.00 kip*ft Vnz = 232.21 kip

COEFFICIENTS:
Fi b = 0.900 Fi c = 0.850 Fi v = 0.900

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) + 8/9*Muy/(Fib*Mny) = 0.973 < 1.000 LRFD (H1-1A)
Vuz/(Fiv*Vnz) = 0.029 < 1.000 LRFD (F2-2)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Nominal strength of an axially loaded compression member ϕ_c*P_n [kips]	627.55	628
2. Nominal moment strength Mny [ft-kips]	650	650
3. Check LRFD Formula (H1-1a)	0.973	0.973

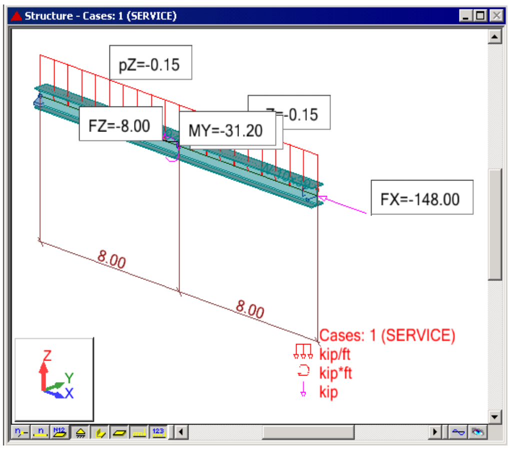
VERIFICATION EXAMPLE 4
- Axial compression and biaxial bending I

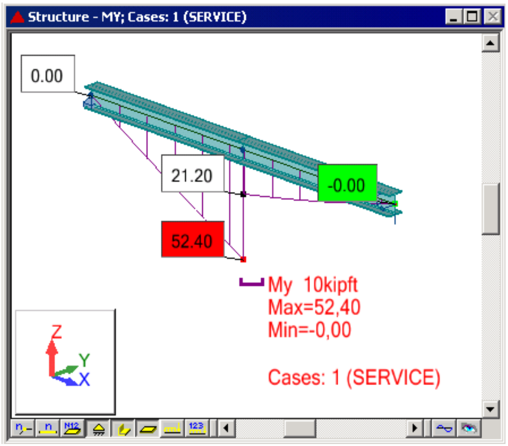
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

TITLE:
Axial compression and biaxial bending (Example 12.13.3).

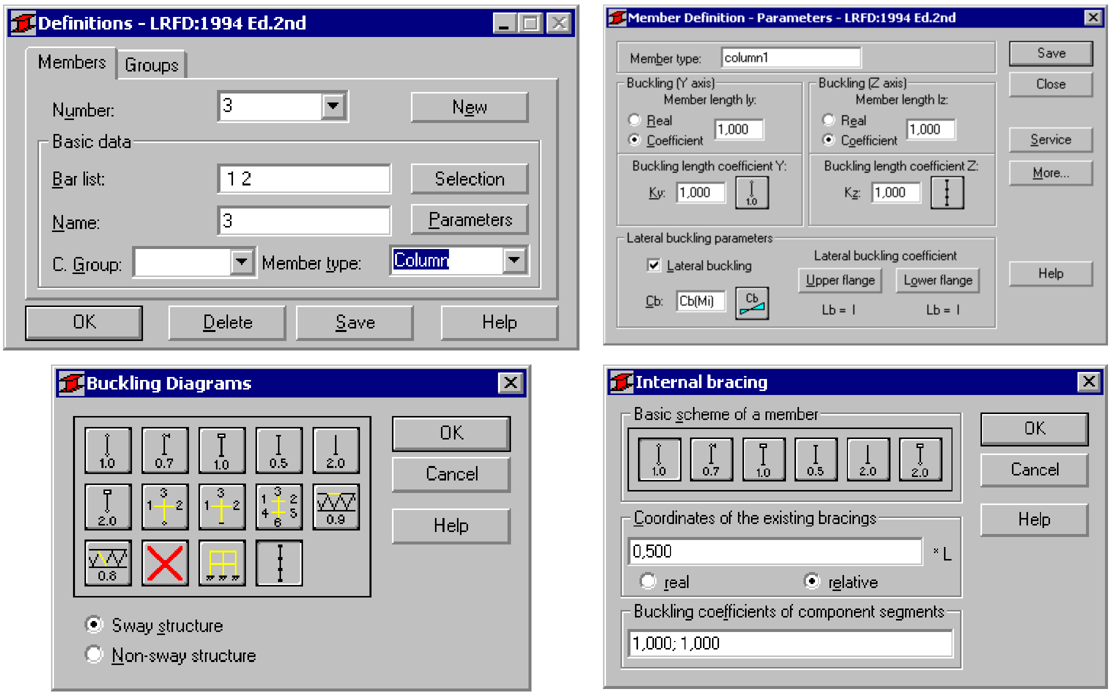
SPECIFICATION:
Design a beam-column W section for the service loading conditions shown below. The compression load P is 30 kips dead load and 70 kips live load. The bracked load W is 2 kips dead load and 18 live load, as might by caused by a crane, and the horizontal load H is 5 kips live load, as might be the horizontal effect of a crane. The member is part of a braced system, has support in the weak direction at mid height, but only at the top and bottom for the strong direction. Use A36 steel and Load and Resistance Factor Design.

- Compute factored loads. Assume a first-order analysis was performed to obtain the given forces:
  Pu = 1.2(30) + 1.6(70) = 148 kips (right site)
  Wu = 1.2(2) + 1.6(18) = 31.2 kips
  Pu =148 + 31.2 = 179 kips (left site)
  Hu = 1.6(5) = 8 kips
  Maximum moment = (H/2 + W/16)*8
  Mnt = (8/2 +31.2/16)8 = 47.6 ft-kips
- Moment magnification for W 10x39 (initially taken for analysis) Mux = B1*Mnt = 1.10*47.6 = 52.4 ft-kips

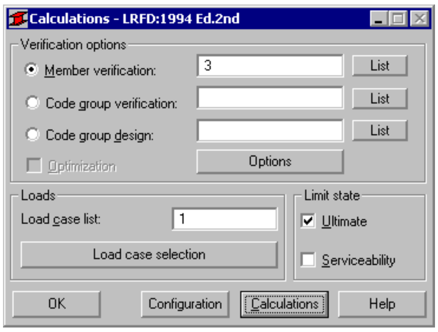




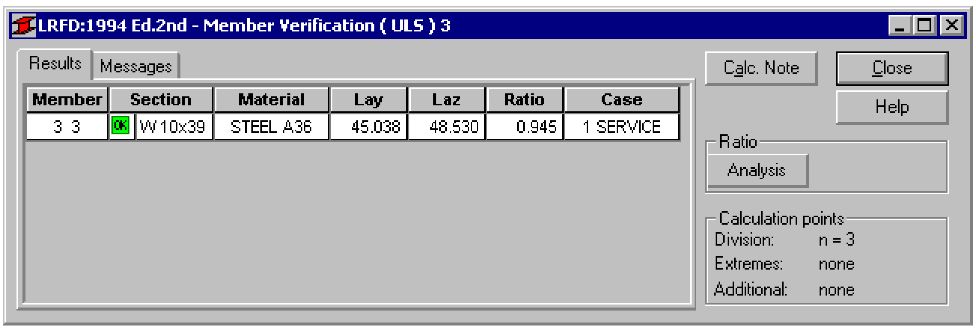
SOLUTION:
Create a new "super-member" consists of the elements 1 and 2. Press the *New* button in DEFINITION-MEMBERS tab. The new member 3 will be automatically created. In editable field *Bar List* type numbers of existing bars 1 2. Define a new type of member. For analysed member 3 pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button that opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **COLUMN1** in the *Member Type* editable field. Then, press *Buckling Length coefficient Z* icon and select the last icon. The new dialog box *Internal bracing* will appear. Define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Save the newly-created type of member.



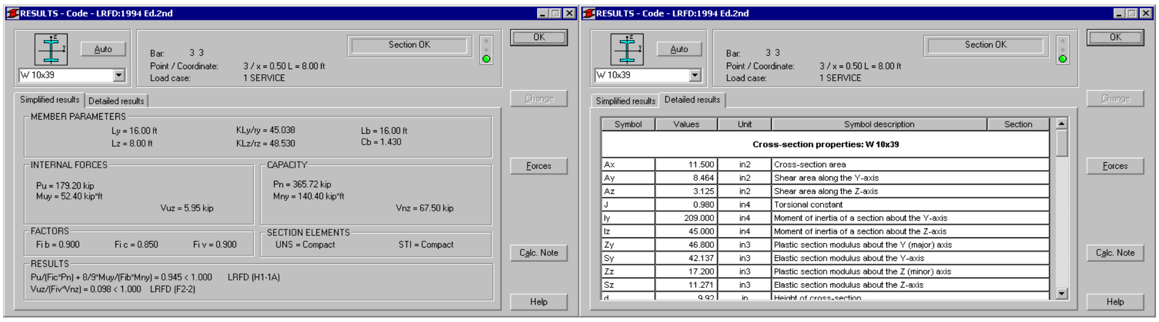
In the CALCULATIONS dialog box set *Member Verification* option for member 3 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button. Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 3 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.



RESULTS:
a) for W 10 x 39



STEEL DESIGN

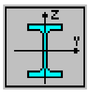
CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 3 **POINT:** 3 **COORDINATE:** x = 0.50 L = 8.00 ft

---

LOADS:
Governing Load Case: 1 SERVICE

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 10x39

d=9.92 in	Ay=8.464 in2	Az=3.125 in2	Ax=11.500 in2
b=7.99 in	Iy=209.000 in4	Iz=45.000 in4	J=0.980 in4
tw=0.32 in	Sy=42.137 in3	Sz=11.271 in3	
tf=0.53 in	Zy=46.800 in3	Zz=17.200 in3	

MEMBER PARAMETERS:

Ly = 16.00 ft	KLy/ry = 45.038	Lb = 16.00 ft
Lz = 8.00 ft	KLz/rz = 48.530	Cb = 1.430

INTERNAL FORCES:		**NOMINAL STRENGTHS:**	
Pu = 179.20 kip		Pn = 365.72 kip	
Muy = 52.40 kip*ft	Vuz = 5.95 kip	Mny = 140.40 kip*ft	Vnz = 67.50 kip

---

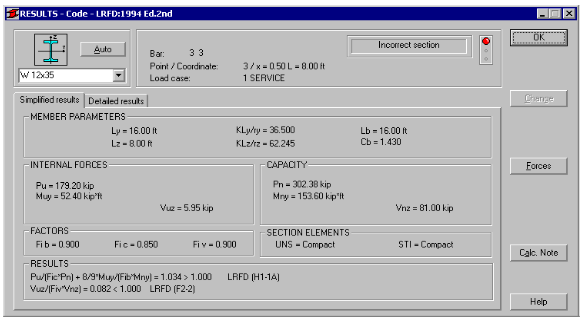
COEFFICIENTS:
Fi b = 0.900 Fi c = 0.850 Fi v = 0.900

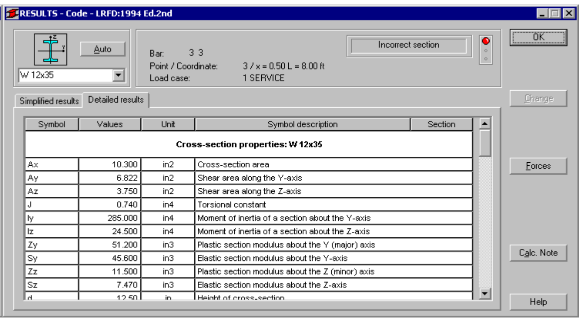
SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) + 8/9*Muy/(Fib*Mny) = 0.945 < 1.000 LRFD (H1-1A)
Vuz/(Fiv*Vnz) = 0.098 < 1.000 LRFD (F2-2)

Section OK !!!

b) check for lighter section W 12 x 35





STEEL DESIGN

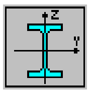
CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 3 **POINT:** 3 **COORDINATE:** x = 0.50 L = 8.00 ft

---

LOADS:
Governing Load Case: 1 SERVICE

MATERIAL:
STEEL A36 Fy = 36.00 ksi



SECTION PARAMETERS: W 12x35

d=12.50 in	Ay=6.822 in2	Az=3.750 in2	Ax=10.300 in2
b=6.56 in	Iy=285.000 in4	Iz=24.500 in4	J=0.740 in4
tw=0.30 in	Sy=45.600 in3	Sz=7.470 in3	
tf=0.52 in	Zy=51.200 in3	Zz=11.500 in3	

MEMBER PARAMETERS:

Ly = 16.00 ft	KLy/ry = 36.500	Lb = 16.00 ft
Lz = 8.00 ft	KLz/rz = 62.245	Cb = 1.430

INTERNAL FORCES:
Pu = 179.20 kip
Muy = 52.40 kip*ft Vuz = 5.95 kip

NOMINAL STRENGTHS:
Pn = 302.38 kip
Mny = 153.60 kip*ft Vnz = 81.00 kip

COEFFICIENTS:
Fi b = 0.900 Fi c = 0.850 Fi v = 0.900

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) + 8/9*Muy/(Fib*Mny) = 1.034 > 1.000 LRFD (H1-1A)
Vuz/(Fiv*Vnz) = 0.082 < 1.000 LRFD (F2-2)

Incorrect section !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
For W10x39 section		
1.Nominal strength of an axially loaded comp. member ϕ_c*P_n [kips]	310.87	311
2. Nominal moment strength Mny [ft-kips]	140.40	140
3. Check LRFD Formula (H1-1a)	0.945	0.94
For W12x35 section		
4.Nominal strength of an axially loaded comp. member ϕ_c*P_n [kips]	257.03	257
5. Nominal moment strength Mny [ft-kips]	153.60	154
6. Check LRFD Formula (H1-1a)	1.034	1.03
7. Check LRFD Formula (H1-1a) for W 14 x 38	0.909	0.91
8. Check LRFD Formula (H1-1a) for W 14 x 34	1.026	1.02

The lightest section that satisfies is the W 14 x 38; however, the extra 4 in. of depth may not be desirable.

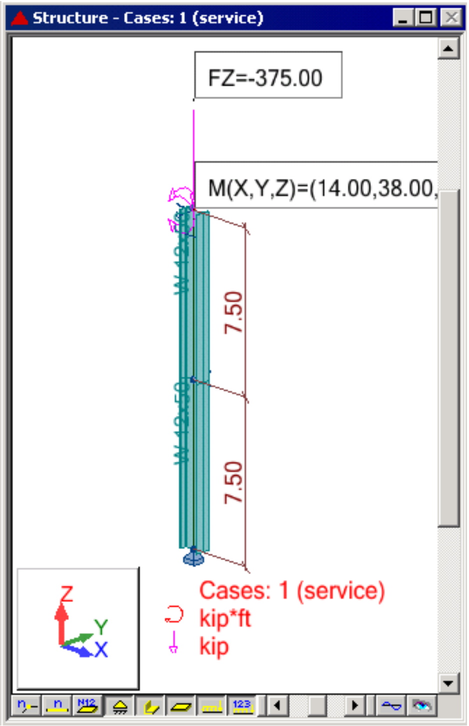
CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

VERIFICATION EXAMPLE 5 - Axial compression and biaxial bending II

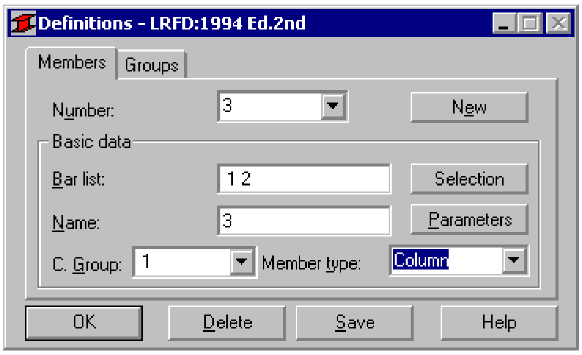
Example taken from STEEL STRUCTURES - Design and Behavior
Emphasizing Load and Resistance Factor Design
Third Edition written by Charles G. Salmon and John E. Johnson

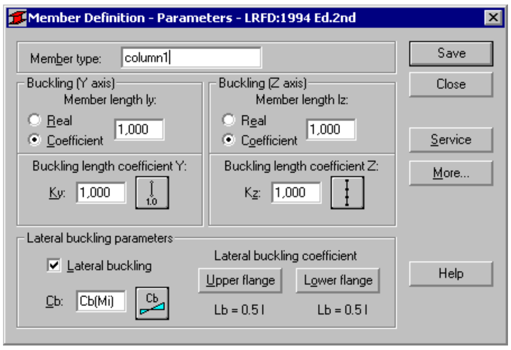
TITLE:
Axial compression and biaxial bending (Example 12.13.7).

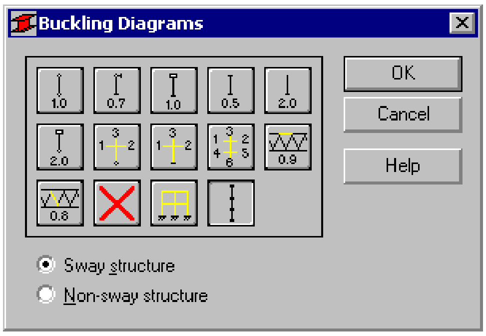
SPECIFICATION:
Select the lightest W12 50 section to carry an axial compression in addition to biaxial bending, loaded as shown below. Assume a first-order structural analysis has been performed using factored load. The results give P_u=375 kips, M_{nty}=38 ft-kips about y-axis at the top of the column, and M_{ntz}=14 ft-kips about the z-axis at the top of column. Use A572 Grade 50 steel and Load and Design Factor Design.

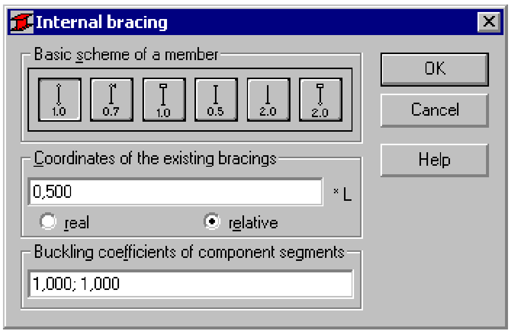


SOLUTION:
Create a new "super-member" consists of the elements 1 and 2. Press the *New* button in DEFINITION-MEMBERS tab. The new member 3 will be automatically created. In editable field *Bar List* type numbers of existing bars 1 2. Define a new type of member. For analysed member 3 pre-defined type of member COLUMN may be initially opened. It can be set in *Member type* combo-box. Press the *Parameters* button that opens MEMBER DEFINITION – PARAMETERS dialog box. Type a new name **Column1** in the *Member Type* editable field. Then, press *Buckling Length coefficient Z* icon and select the last icon. The new dialog box *Internal bracing* will appear. Define internal support in the middle of the member by typing value 0.5 in the *Coordinates of the existing bracings* field. For defining appropriate values of lateral buckling parameters choose the icon Cb that opens *Parameter Cb* dialog box and double-click the second icon (Moments at the ends). Additionally set 0.5 coefficient in lateral buckling length Lb editable field. Save the newly-created type of member.

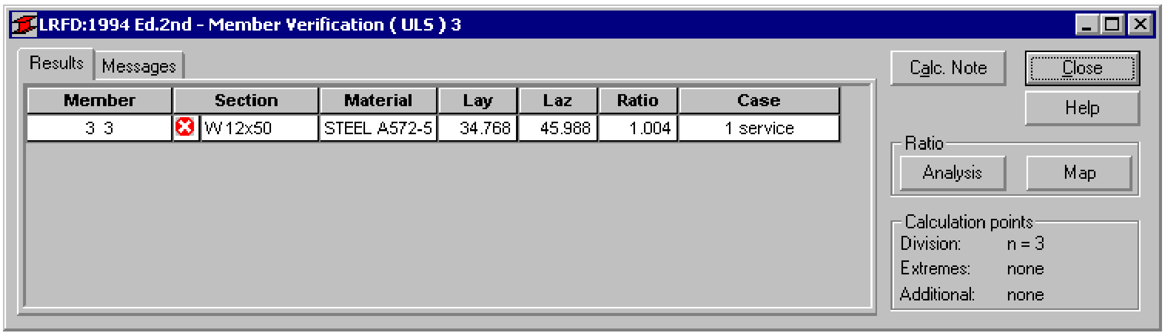




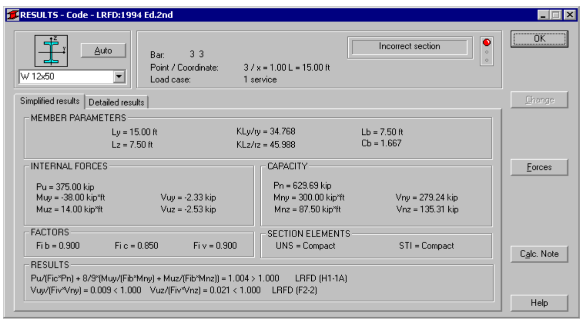


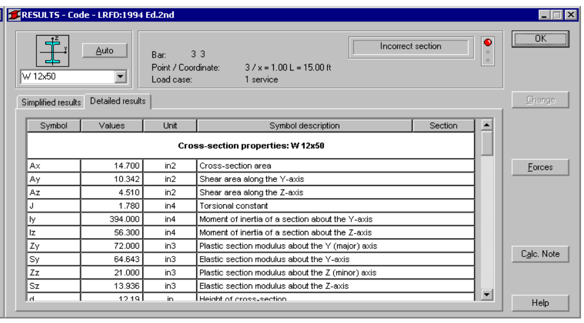


In the CALCULATIONS dialog box set *Member Verification* option for member 3 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analyzed). Now, start the calculations by pressing *Calculations* button. Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for the member 3 opens the RESULTS dialog box with detailed results for the analyzed member.



The view of the RESULTS window is presented below. Moreover, the printout note containing the same results data as in *Simplified results* tab of the RESULTS window is added.





STEEL DESIGN

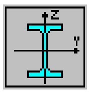
CODE: *LRFD Second Edition*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 3 3 **POINT:** 3 **COORDINATE:** x = 1.00 L = 15.00 ft

---

LOADS:
Governing Load Case: 1 service

MATERIAL:
STEEL A572-50 Fy = 50.00 ksi



SECTION PARAMETERS: W 12x50

d=12.19 in	Ay=10.342 in2	Az=4.510 in2	Ax=14.700 in2
b=8.08 in	Iy=394.000 in4	Iz=56.300 in4	J=1.780 in4
tw=0.37 in	Sy=64.643 in3	Sz=13.936 in3	
tf=0.64 in	Zy=72.000 in3	Zz=21.000 in3	

MEMBER PARAMETERS:

Ly = 15.00 ft	KLy/ry = 34.768	Lb = 7.50 ft
Lz = 7.50 ft	KLz/rz = 45.988	Cb = 1.667

INTERNAL FORCES:

Pu = 375.00 kip	Vuy = -2.33 kip
Muy = -38.00 kip*ft	Vuz = -2.53 kip
Muz = 14.00 kip*ft	

NOMINAL STRENGTHS:

Pn = 629.69 kip	Vny = 279.24 kip
Mny = 300.00 kip*ft	Vnz = 135.31 kip
Mnz = 87.50 kip*ft	

COEFFICIENTS:
Fi b = 0.900 Fi c = 0.850 Fi v = 0.900

SECTION ELEMENTS:
UNS = Compact STI = Compact

VERIFICATION FORMULAS:
Pu/(Fic*Pn) + 8/9*(Muy/(Fib*Mny) + Muz/(Fib*Mnz)) = 1.004 > 1.000 LRFD (H1-1A)
Vuy/(Fiv*Vny) = 0.009 < 1.000 Vuz/(Fiv*Vnz) = 0.021 < 1.000 LRFD (F2-2)

Incorrect section !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1.Nominal strength of an axially loaded comp. member ϕ_c*P_n	535.24	535
2. Nominal moment strength Mny [ft-kips]	300.00	301.1
3. Nominal moment strength Mnz [ft-kips]	87.5	89.2
4. Check LRFD Formula (H1-1a)	1.004	0.98

CONCLUSIONS:
The differences are caused by different way of rounding-off the cross-sectional properties (cross-sectional area, section modulus, moment of inertia).

CONCRETE

1. ACI 318-02 – RC columns

VERIFICATION EXAMPLE 1
- Column subjected to axial load and uni-axial bending I

Example based on:
[2] E. G. Nawy, "Reinforced Concrete. A Fundamental Approach", Fifth Edition, 1987, Example 9.15, pp. 372

DESCRIPTION OF THE EXAMPLE:

Rectangular tied column is subjected to uni-axial bending. Design the column section and reinforcement necessary for gravity loads only, assuming lateral sideway due to wind as negligible.

In the following example, the results of the program, concerning the calculations of reinforcement and buckling analysis are compared to the results of [2]. Moreover, in order to better verify the results, manual calculations are carried out in parallel.

LOADS:

P_u=726	[kip]
M_1=46	[kip-ft]
M_2=127	[kip-ft]

GEOMETRY:

l_u=18	[ft]
cross section: 21x21	[in]

MATERIAL:

Concrete:	f'_c= 5000	[psi],	$E_c = 4.29 \times 10^6$	[psi]
Steel:	f_y= 60000	[psi],	$E_s = 2.9 \times 10^6$	[psi]

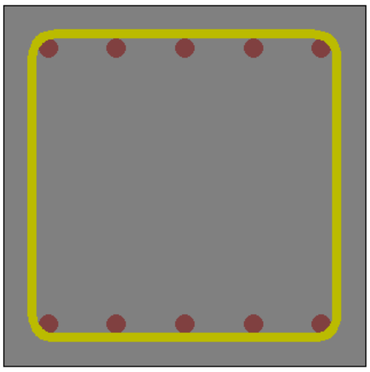


Fig.1. Cross section with reinforcement determined in [2] (10 No.9).

IMPORTANT STEPS:

In the dialog box *Buckling length* set buckling parameter k_y as 1.7 *(Fig.1.2.).*

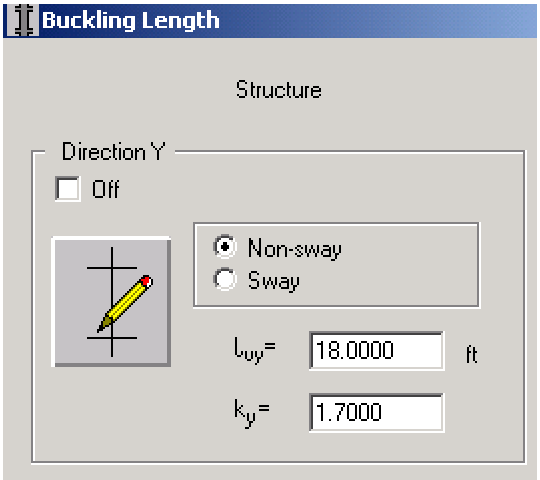


Fig. 1.2. Buckling parameters of the column.

In the *Loads* dialog box put the axial force *N*, moments at the ends of the column M_yA, M_yB, and the moment in the mid-height $M_yC = M_yA$, since the authors of [2] assume C_m=1 *(Fig.1.3.).*

No.	Case	Nature	Group	N (kip)	MyA (kip*ft)	MyB (kip*ft)	MyC (kip*ft)	MzA (kip*ft)	MzB (kip*ft)	MzC (kip*ft)	β	γ
1	OBL.1	design	1	726.00	46.00	127.00	127.00	0.00	0.00	0.00	0.50	1.00
*												

Fig. 1.3. Loads.

In the *Calculation Option/ General* dialog box check: *Design – unidirectional bending: My direction (Fig. 1.4.).*

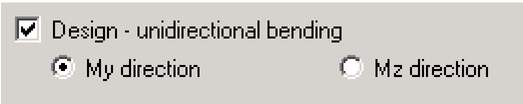


Fig. 1.4. Unidirectional bending.

RESULTS OF REINFORCEMENT CALCULATION:

The reinforcement generated by the program *(Fig 1.5.)* is different than that calculated in [2]. The authors of [2] find the reinforcement of 5 No. 9 bars at each side, thus the total area is equal to 10.99in^2. The calculations with the program result in reinforcement with 20 No. 6 bars, thus the total area is equal to 8.84 in^2. The reinforcement determined by the program is more optimal solution. It should be noted, that if we fix the bars diameter as No. 9 (Reinforcement pattern dialog), we obtain the same reinforcement as the authors of [2] (five No. 9 bars at each side).

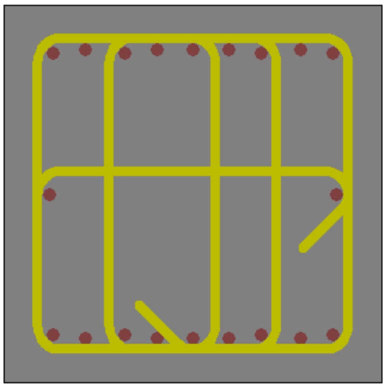


Fig. 1.5. Reinforcement generated by the program (20 No. 6).

In order to verify the results of buckling analysis, after the modification of reinforcement to the form as in [2], the verification is carried out.

RESULTS OF BUCKLING ANALYSIS:

Quality	**Formula number in [1]** (Unit)	[2]	Robot	Manual calculations
$\frac{kl_u}{r}$	10.7 (-)	58.2	60.5723	60.5723
I_g	(in^4)	16207	16207	16207
I_{se}	(in^4)	-	640	640
$EI = \max\begin{cases}\frac{(0{,}2E_cI_g + E_sI_{se}}{1+\beta d} \\ \frac{0{,}4E_cI_g}{1+\beta_d}\end{cases}$	10.11, 10.12 (kip-ft^2)	128634 uses only 10.12	150194	150206
$P_c = \frac{\pi^2 EI}{(kl_u)^2}$	10.10 (kip)	1356	1583	1583
$C_m = 1{,}0$	10.13 (-) *10.12.3.1	1,0	1,0	1,0
$\delta_{ns} = \max\begin{cases}\frac{C_m}{1-\frac{P_u}{0{,}75P_c}} \\ 1\end{cases}$	10.9 (-)	3.495	2.57	2.57
$M_2 = \max\begin{cases}M_2 \\ P_u(0{,}6+0{,}003h)\end{cases}$	10.14 (kip-ft)	127	127	127
$M_c = \delta_{ns}M_2$	10.8 (kip-ft)	444.16	326.86	326.82

FINAL VERIFICATION:

NOTE: the results of reinforcement calculation concern the automatic calculation of reinforcement. In the case of buckling analysis, the reinforcement obtain in the program is modified to a form as in the reference example, in order to enable the comparison of total moments.

Quantity	[2]	Robot
A_s	10.99 in^2	8.84 in^2
M_c	444.16 kip-ft	326.82 kip-ft *

***** The reason of greater final moment determined in [2] is the use of equation 10.12 only. Robot uses the maximum of values from equation 10-11 and 10-12, thus the critical force is calculated more accurately.

VERIFICATION EXAMPLE 2
- Column subjected to axial load and uni-axial bending II

Example based on:
[3] S.K. Ghosh, D.A. Fanella, B.G. Rabbat 'Notes on ACI 318-95. Building code requirements for structural concrete', First Edition, 1996, Example 13.1, page 13-21

DESCRIPTION OF THE EXAMPLE:

Design A3 column in the non-sway frame.

In the following example, the results of the program, concerning the calculations of buckling are compared to the results of [3]. Moreover, in order to better verify the results, manual calculations of slenderness effects are carried out in parallel.

Finally, the calculations of reinforcement and calculations of capacity are compared to the results of the *pcaColumn* v.3.64 software.

LOADS:

$P_u = 1096$	[kip]
$M_{u.top} = 116.2$	[kip-ft]
$M_{u.bot} = 59.3$	[kip-ft]

GEOMETRY:

l_u=21.33	[ft]
cross section: 20x20	[in]

MATERIAL:

Concrete:	f'_c=5000	[psi],	E_c=4.29x10^6	[psi]
Steel:	f_y=60000	[psi],	E_s= 2.9x10^6	[psi]

IMPORTANT STEPS:

In the dialog box *Buckling length* set buckling parameter k_y as 0.84.

In order to obtain the same Young modulus as in [3], the unit weight of concrete should be set as 0.144[kip/ft^3].

In the *Loads* dialog box put the axial force *N*, moments at the ends of the column M_yA, M_yB *(Fig. 2.1.)* Let the M_yC in the mid-height be calculated automatically.

No.	Case	Nature	Group	N (kip)	MyA (kip*ft)	MyB (kip*ft)	MyC (kip*ft)	MzA (kip*ft)	MzB (kip*ft)	MzC (kip*ft)	β	γ
1	OBL.1	design	1	1096.00	116.20	59.30	93.44	0.00	0.00	0.00	0.82	1.00
*												

Fig. 2.1. Loads.

In the *Calculation Options*/*General* dialog box check: *Design – unidirectional bending: My direction.*

RESULTS OF REINFORCEMENT CALCULATION:

The reinforcement generated by the program *(Fig. 2.3.)* is different than that assumed for all calculations in the reference [3]. However, the latter one does not fulfill the capacity requirements (in [3] it is increased up to 8 bars No.9, but after the calculations).
Nevertheless, the reinforcement has been modified (*Fig. 2.4*) in the program (the number of bars has been decreased down to 8 bars No.7), in order to compare the results of buckling analysis with the results from [3].

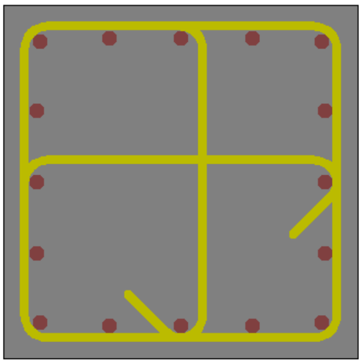


Fig. 2.3. Reinforcement generated automatically by the program (16 No.7).

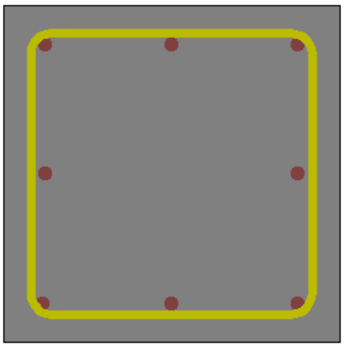


Fig. 2.4. Manually modified reinforcement (8 No.7), equal to that assumed for calculations in [3].

RESULTS OF BUCKLING ANALYSIS:

Quantity	**Formula number in [1]** (Unit)	[3]	Robot	Manual calculations
$\frac{kl_u}{r}$	10.7 (-)	36	37	37
I_g	(in^4)	13333	13333	13333
I_{se}	(in^4)	213	213	213

$EI = \max\begin{cases} \dfrac{(0{,}2E_cI_g + E_sI_{se}}{1+\beta d} \\ \dfrac{0{,}4E_cI_g}{1+\beta_d} \end{cases}$	10.11, 10.12 (kip-in^2)	11.8x10^6	**11.8x10^6**	11.8x10^6
$P_c = \dfrac{\pi^2 EI}{(kl_u)^2}$	10.10 (kip)	2519	2523	2523
$C_m = \max\begin{cases} 0{,}6 + 0{,}4\dfrac{M_1}{M_2} \\ 0{,}4 \end{cases}$	10.13 (-)	0.8	0.8	0.8
$\delta_{ns} = \max\begin{cases} \dfrac{C_m}{1-\dfrac{P_u}{0{,}75P_c}} \\ 1 \end{cases}$	10.9 (-)	1.9	1.93	1.91
$M_2 = \max\begin{cases} M_2 \\ P_u(0{,}6+0{,}003h) \end{cases}$	10.14 (kip-ft)	$\max\begin{cases}116.2\\109.6\end{cases}$	$\max\begin{cases}116.2\\109.6\end{cases}$	$\max\begin{cases}116.2\\109.6\end{cases}$
$M_c = \delta_{ns}M_2$	10.8 (kip-ft)	220.8	222.1	222.1

FINAL VERIFICATION:

NOTE: the results of reinforcement calculation concern the automatic calculation of reinforcement. In the case of buckling analysis, the reinforcement obtained in the program is modified to a form as in the reference example, in order to enable the comparison of total moments.

Quantity	[2]	
A_s	7.99 in^2	9.62 in^2
M_c	220.8 kip-ft	222.1kip-ft

VERIFICATION WITH THE OTHER SOFTWARE:

According to the current code [1], the reinforcement 8 No.9 assumed finally in the reference [3] is not sufficient. Thus, we let Robot to calculate the reinforcement automatically (see Fig. 2.3), and then check the results with ***pcaColumn*** v.3.64 software.

Quantity	***pcaColumn*** v.3.64	Robot
M_c	214.8 kip-ft	222.1kip-ft
capacity (interaction diagrams)	see Fig. 2.5	

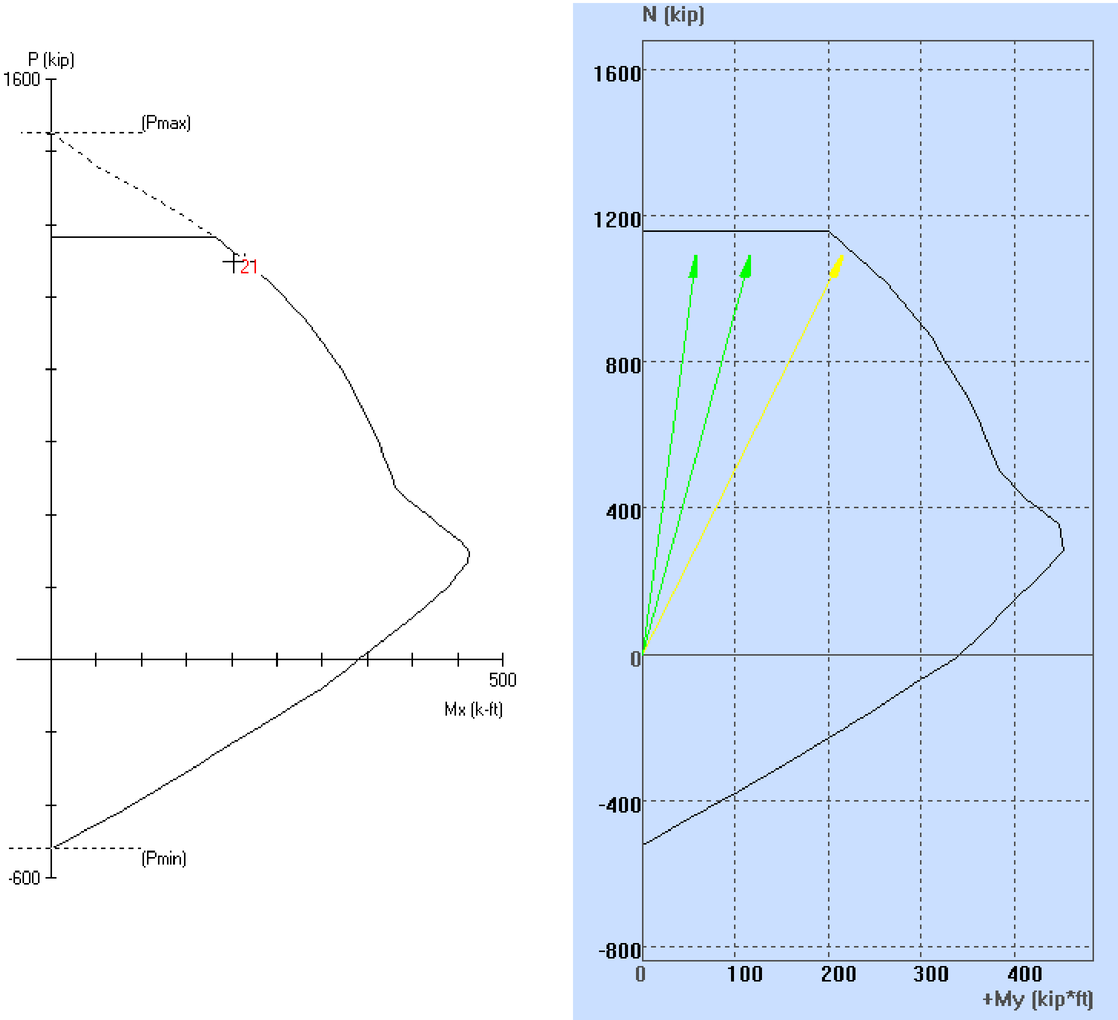


Fig. 2.5. Comparison of the interaction diagrams

CONCLUSIONS:

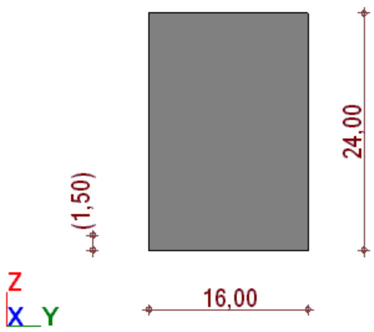
The results of the calculations of slenderness effects are with agreement with those from [3].
The results verified against the software ***pcaColumn*** v.3.64 show that the calculations of slenderness effects and of capacity are correct.

VERIFICATION EXAMPLE 3
- Column subjected to axial load and biaxial bending

DESCRIPTION OF THE EXAMPLE:

Following example illustrates the procedure of dimensioning of biaxial bending of column, which is non-sway in one direction, whereas sway in the other. The results of the program are accompanied by the 'manual' calculations.

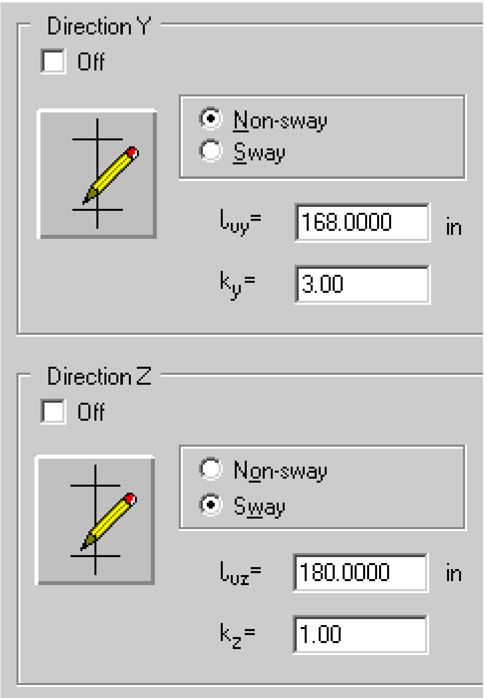
1. SECTION DIMENSIONS



2. MATERIALS

Concrete: $f_{c'}$ = 3.50 (ksi)
Longitudinal reinforcement: Grade 60 f_y = 60.00 (ksi)
Transversal reinforcement: Grade 60 f_y = 60.00 (ksi)

3. BUCKLING MODEL



As can be seen the sway column is assumed for Z direction, and the non-sway column for Y direction

4. LOADS

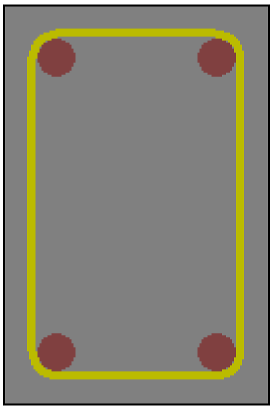
No.	Case	Nature	Group	N (kip)	MyA (kip*ft)	MyB (kip*ft)	MyC (kip*ft)	MzA (kip*ft)	MzB (kip*ft)	MzC (kip*ft)	Mnsz/ Mz	β	γ
1	DL1	dead load	1	250.00	40.00	60.00	52.00	60.00	80.00	90.00	0.40	0.30	1.20
2	LL1	live load	1	150.00	20.00	10.00	16.00	0.00	10.00	12.00	0.60	0.50	1.60
*													

NOTE: The column is sway for Z direction, thus the ratio of non-sway moment to total moment should be defined in the load table.

NOTE: Let us assume, the moments in Y direction are linearly distributed along the height of the column. Thus, we define only the ends' moments for Y direction. In Z direction however, we assume the mid-height moment is not a result of the linear distribution. For such a case, Robot let the user define the moments in the mid-section explicitly.

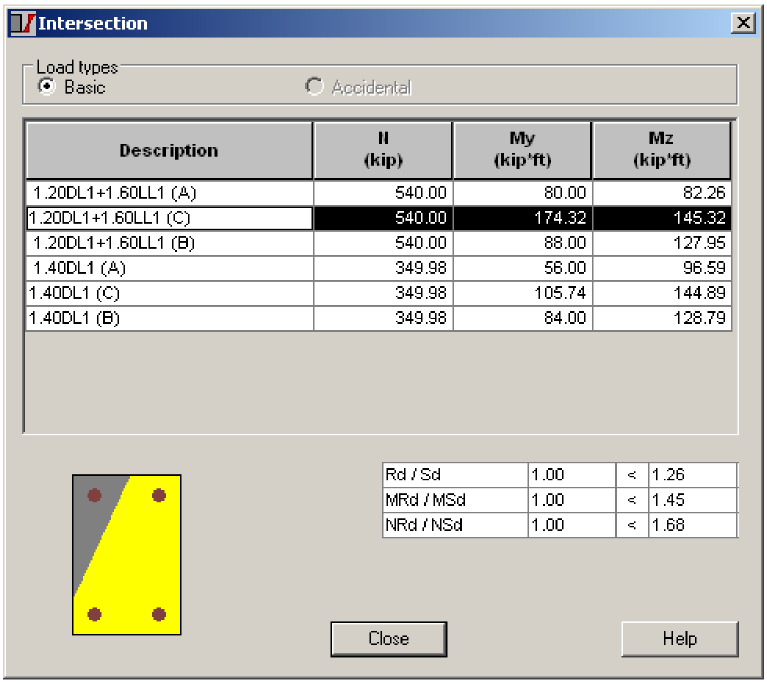
5. CALCULATED REINFORCEMENT:

The program generates the reinforcement 4 No.18.



6. RESULTS OF THE SECTION CALCULATIONS:

The dimensioning combination is **1.2 DL1+1.6 LL1**
The dimensioning section (where the most unfavorable set of forces is found) is for that combination the section in the mid-height of the column.



Since the column is found as slender, the second-order effects are taken into account in both directions.

In parallel the other sections (at the ends of the column) are checked for all combinations of loads.
In the top and bottom ends' sections of the column in Y direction, the influence of buckling has not been taken into account, since the structure is non-sway in this direction. In Z direction however, the influence of slenderness is taken into account for all three sections of the column.
All the results of total forces for each combination and each section of the column may be seen in the table "Intersection" at the Column-results layout.

7. CALCULATIONS OF TOTAL MOMENT:

7.1. LOADS

For the dimensioning combination, the loads are:

	Case	N (kip)	MyA (kip-ft)	MyB (kip-ft)	MyC (kip-ft)	MzA (kip-ft)	MzB (kip-ft)	MzC (kip-ft)
1	G1	250	40	60	52	60	80	90*
2	Q1	150	20	10	16	0	10	12*
Dimensioning combination	1.2G1+1.6Q1	540	80	88	84.8	72	112	127.2

where A, B and C denote upper, lower and mid-height sections of the column respectively.
* - the values are written "by hand" by the user (see point 4 – Loads)

7.2. THE INFLUENCE OF SLENDERNESS

Two independent calculations of the total moment for both directions are carried out.

Y DIRECTION

Slenderness:

$\frac{k \cdot l_u}{r}$ = 72.25

$k \cdot l_u$ = 504 (in)

r = 6.93 (in)

$34 - 12\frac{M1}{M2}$ = 23.09

$\frac{M1}{M2}$ = 0.909

$\frac{k \cdot l_u}{r} > 34 - 12\frac{M1}{M2}$ column is slender

The initial moments at the end of the column:

M1 = 80.00 (kip-ft) M2 = 88.00 (kip-ft)

Calculation of critical force:

$$P_c = \frac{\pi^2 EI}{(kl_u)^2}$$

$$EI = \max\begin{cases}\frac{(0{,}2E_c I_g + E_s I_{se})}{1+\beta_d} \\ \frac{0{,}4E_c I_g}{1+\beta_d}\end{cases} \qquad \text{(10-11), (10-12)}$$

$I_s = As \cdot z^2 = 16.00 \cdot (12 - 3.1285)^2$ =1259.5 in^4

I_g =18432.00 in^4

E_c = 3686.82 ksi

E_s = 29000.00 ksi

β_d is calculated as a weighted average from the load cases. The weight factors are assumed according to the axial forces. Thus:

$\beta_d = \frac{1.2 \cdot 250}{540}0.3 + \frac{1.6 \cdot 150}{540}0.5$ =0.389

$$EI = \max\begin{cases}\frac{(0{,}2E_c I_g + E_s I_{se})}{1+\beta_d} = 36081620 \text{ kip - in}^2 \\ \frac{0{,}4E_c I_g}{1+\beta_d} = 19569609 \text{ kip - in}^2\end{cases}$$

Thus,

$EI = 36081620$ kip-in^2

$P_c = 1402$ kip

The coefficient δ_{ns}:

$$\delta_{ns} = \frac{C_m}{1 - \frac{P_u}{0{,}75 P_c}} = 1.981$$

$$C_m = \max \begin{cases} 0.6 + 0.4 \frac{M_1}{M_2} \\ 0.4 \end{cases} = 0.964$$

$$M_2 = \max \begin{cases} M_2 = 88\, kip - ft \\ P_u (0{,}6 + 0{,}003h) = 540 \cdot 0.11 = 59.4 kip - f \end{cases} = 88 \text{ (kip-ft)}$$

The dimensioning moment in Y direction is equal to:

$M_c = \delta_{ns} M_2$ = 174.3 (kip-ft)

Z DIRECTION

NOTE: In most cases, the sway column is calculated for the end moment M2, taking into account the effects of slenderness.
In this case however, the presence of moment in Y direction (which is also increased due to slenderness), causes the mid-height section to be the most unfavorable (even though the end moment in Z direction is greater).

Slenderness:

$\frac{k \cdot l_u}{r}$ = 38.97

$k \cdot l_u$ = 504 (in)

r = 6.93 (in)

$\frac{k \cdot l_u}{r} > 22$ the column is slender

The following table illustrates how the division of moments into sway and non-sway is carried out for the particular load combination.

Case	MzC	Load factors	MzC (dimensioning combination)	Mzns/Mz	Mzns = (Mzns/Mz)*Mz	Mzs = (1-Mzns/Mz)*Mz
G1	72	1.2	108	0.4	43.2	64.8
Q1	6	1.6	19.2	0.6	11.52	7.68
SUM		-	96	-	54.72	72.48

$M_{ns} =$ 54.72 (kip-ft)

$M_s =$ 72.48 (kip-ft)

The magnification factor for sway column is equal to:

$\delta_s = 1/(1-Q) = 1.25$ (Q coefficient is defined in the Story parameters dialog box)

The dimensioning moment in Z direction is equal to:

$M_c = \delta_s M_s + M_{ns}$ = 145.32 kip-ft

<u>NOTE</u>: Since the values of moment do not result from the linear distribution, but were defined directly by the user, we do not deal here with M_1 and M_2, but use directly the value of the mid-height moment).

Check if further magnification of the moment is necessary:

$$\frac{l_u}{r} < \frac{35}{\sqrt{\frac{P_u}{f'_c A_g}}}$$

$\frac{l_u}{r}$ = 38.97

$\frac{35}{\sqrt{\frac{P_u}{f'_c A_g}}}$ = 55.22

No further magnification of moment is required.

7.3. FINAL RESULT

M_{cy} = 174.3 (kip-ft)

M_{cz} = 145.32 kip-ft

8. CONCLUSIONS

The algorithm of calculations of the total moments (i.e. slenderness effects) in non-sway/sway column has been presented. The results obtained with the program (see point 6 – Results of the Section Calculations) are in agreement with the manual calculations (see point 7.3 – Final Result).

LITERATURE

[1] ACI 318-02 CODE EDITION
[2] Edward G. Navy:'Reinforced Concrete', 1987, Fifth Edition
[3] S. K. Ghosh: 'Notes on ACI 318-95. Building code requirements for structural concrete', 1996, First Edition.