Autodesk®
Robot™ Structural Analysis Professional

VERIFICATION MANUAL

FOR BRITISH CODES

March 2014

INTRODUCTION

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

All 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

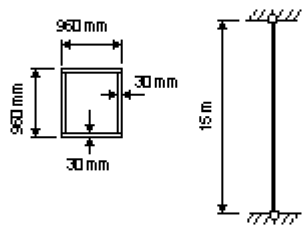
1. BS 5950-Part 1:1985

VERIFICATION EXAMPLE 1
- Column example (Welded box)

Example taken from STEEL DESIGNERS MANUAL,
Editors: Graham W. Owners and Peter R. Knowles, Fifth edition.

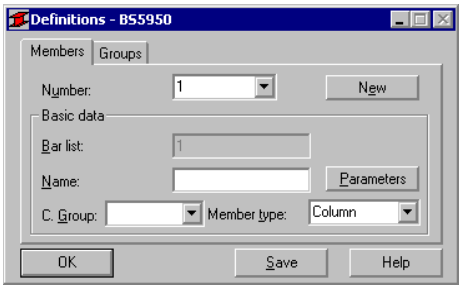
TITLE:
Column example. Welded box. See page 399.

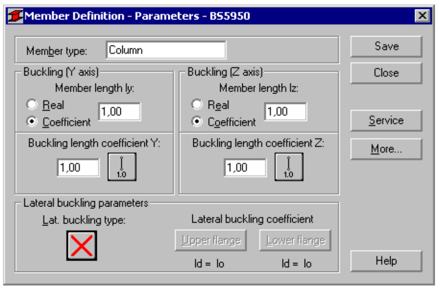
SPECIFICATION:



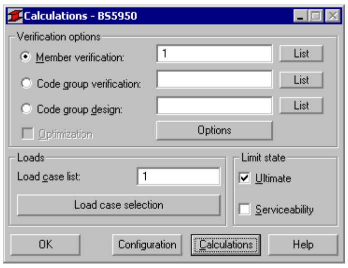
Check the ability of a 960 mm square box column fabricated from 30 mm thick grade 50 plate to withstand an axial compressive load of 22000 kN over an unsupported height of 15 m assuming that both ends are held in position but are provided with no restraint in direction. Design to BS 5950: Part1.

SOLUTION:
Ascribe pre-defined type of member COLUMN with appropriate set of code parameters for the analysed member. It could be done in DEFINITIONS dialog box on the MEMBERS tab.

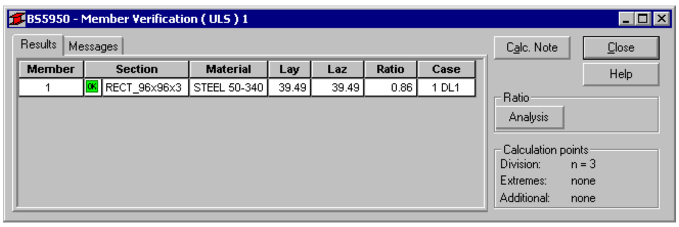




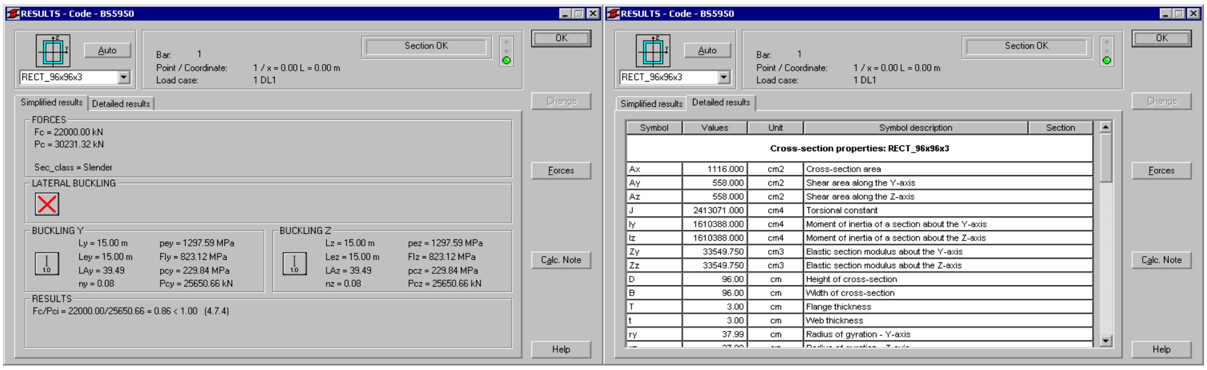
In the CALCULATIONS dialog box, set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analysed). Now, start the calculations by pressing *Calculations* button.



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 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.



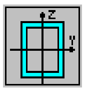
STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

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

LOADS:
Governing Load Case: 1 DL1

MATERIAL:
STEEL 50-340 py = 270.89 MPa



SECTION PARAMETERS: RECT_96x96x3

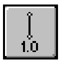
D=96.00 cm

B=96.00 cm	Ay=558.000 cm2	Az=558.000 cm2	Ax=1116.000 cm2
t=3.00 cm	Iy=1610388.000 cm4	Iz=1610388.000 cm4	J=2413071.000 cm4
T=3.00 cm	Zy=33549.750 cm3	Zz=33549.750 cm3	

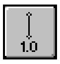
INTERNAL FORCES AND CAPACITIES:
Fc = 22000.00 kN
Pc = 30231.32 kN
Sec_class = Slender

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:



About Y axis:



About Z axis:

Ly = 15.00 m	pey = 1297.59 MPa	Lz = 15.00 m	pez = 1297.59 MPa
Ley = 15.00 m	FIy = 823.12 MPa	Lez = 15.00 m	FIz = 823.12 MPa
LAy = 39.49	pcy = 229.84 MPa	LAz = 39.49	pcz = 229.84 MPa
ny = 0.08	Pcy = 25650.66 kN	nz = 0.08	Pcz = 25650.66 kN

VERIFICATION FORMULAS:
Fc/Pci = 22000.00/25650.66 = 0.86 < 1.00 (4.7.4)

Section OK !!!

COMPARISON:

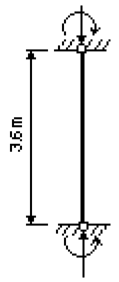
Resistance, interaction expression	Robot	Handbook
1. Compression resistance Pcy	25650.66	25700.00

VERIFICATION EXAMPLE 2
- Beam/Column example (Rolled universal column)

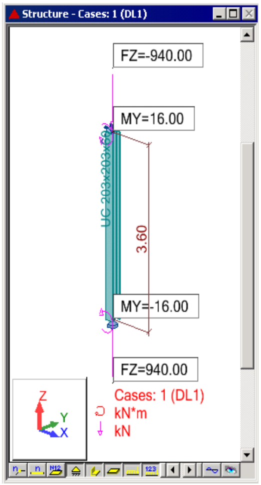
Example taken from STEEL DESIGNERS MANUAL,
Editors: Graham W. Owners and Peter R. Knowles, Fifth edition.

TITLE:
Beam-Column example. Rolled universal column. See page 519.

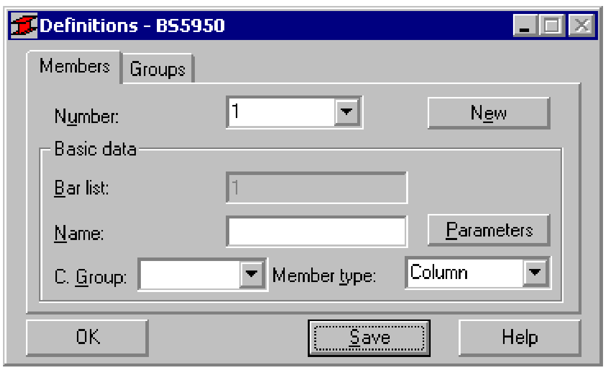
SPECIFICATION:

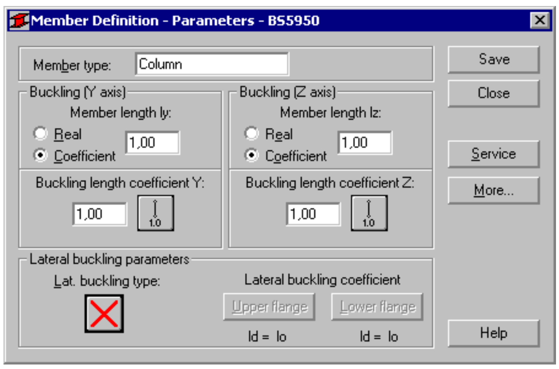


Select the suitable UC in grade 43 steel to carry safely a combination of 940 kN in direct compression and a moment about the minor axis of 16 kNm over an unsupported height of 3.6 m. Problem is one of uniaxial bending producing failure by buckling about the minor axis. Since no information is given on distribution of applied moments make conservative assumption of uniform moment (β=1.0). Try 203x203x60 UC - member capacities suggest Pcy of approximately 1400 kN will provide correct sort of margin to carry the moment.

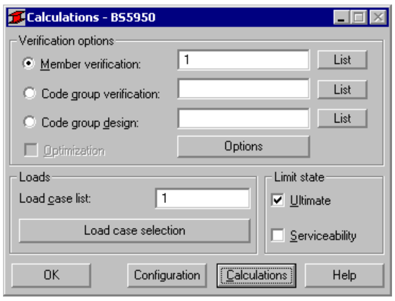


SOLUTION:
For the analysed member, the pre-defined type of member COLUMN with appropriate set of code parameters was ascribed. It could be done in DEFINITIONS dialog box on the MEMBERS tab.

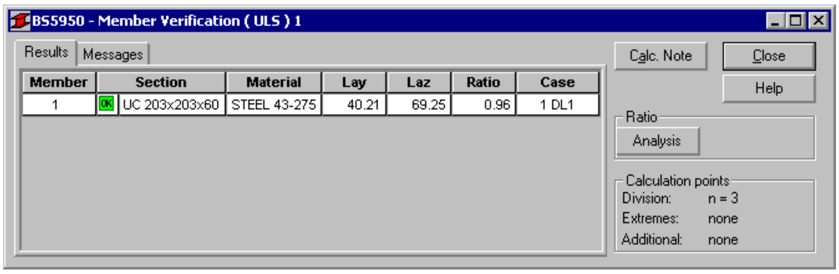




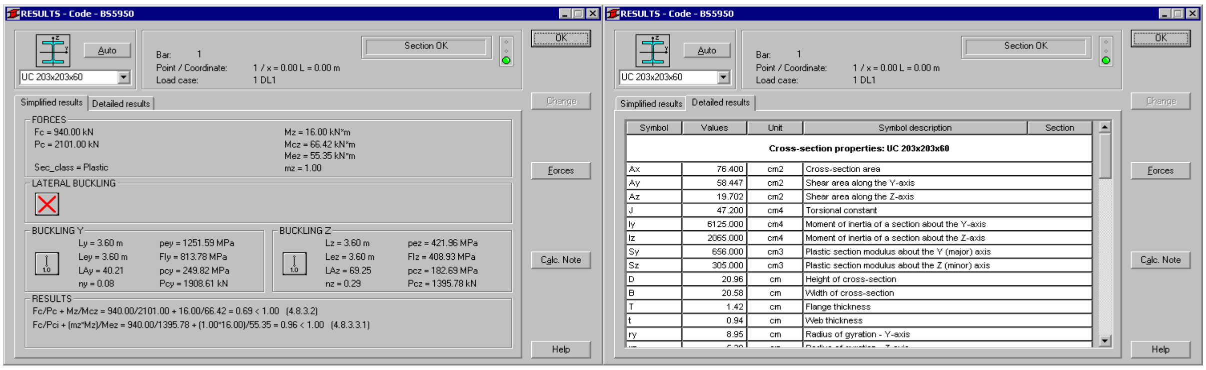
In the CALCULATIONS dialog box, set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit State will be analysed). Now start the calculations by pressing *Calculations* button.



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: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

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

LOADS:
Governing Load Case: 1 DL1

MATERIAL:
STEEL 43-275 py = 275.00 MPa

SECTION PARAMETERS: UC 203x203x60

D=20.96 cm

B=20.58 cm	Ay=58.447 cm2	Az=19.702 cm2	Ax=76.400 cm2
t=0.94 cm	Iy=6125.000 cm4	Iz=2065.000 cm4	J=47.200 cm4
T=1.42 cm	Sy=656.000 cm3	Sz=305.000 cm3	

INTERNAL FORCES AND CAPACITIES:

Fc = 940.00 kN	Mz = 16.00 kN*m
Pc = 2101.00 kN	Mcz = 66.42 kN*m
	Mez = 55.35 kN*m
Sec_class = Plastic	mz = 1.00

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:

About Y axis:		About Z axis:	
Ly = 3.60 m	pey = 1251.59 MPa	Lz = 3.60 m	pez = 421.96 MPa
Ley = 3.60 m	FIy = 813.78 MPa	Lez = 3.60 m	FIz = 408.93 MPa
LAy = 40.21	pcy = 249.82 MPa	LAz = 69.25	pcz = 182.69 MPa
ny = 0.08	Pcy = 1908.61 kN	nz = 0.29	Pcz = 1395.78 kN

VERIFICATION FORMULAS:
Fc/Pc + Mz/Mcz = 940.00/2101.00 + 16.00/66.42 = 0.69 < 1.00 (4.8.3.2)
Fc/Pci + (mz*Mz)/Mez = 940.00/1395.78 + (1.00*16.00)/55.35 = 0.96 < 1.00 (4.8.3.3.1)

Section OK !!!

COMPARISON:

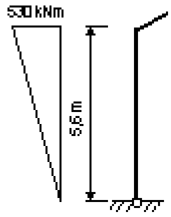
Resistance, interaction expression	Robot	Handbook
1. Compression resistance Pcz	1395.78	1387.00
2. Verification formula (4.8.3.3.1)	0.96	0.97

VERIFICATION EXAMPLE 3
- Beam/Column example (Rolled universal column)

Example taken from STEEL DESIGNERS MANUAL,
Editors: Graham W. Owners and Peter R. Knowles, Fifth edition.

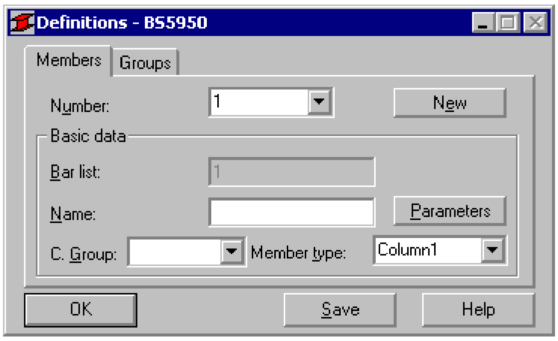
TITLE:
Beam-Column example. Rolled universal column. See page 521.

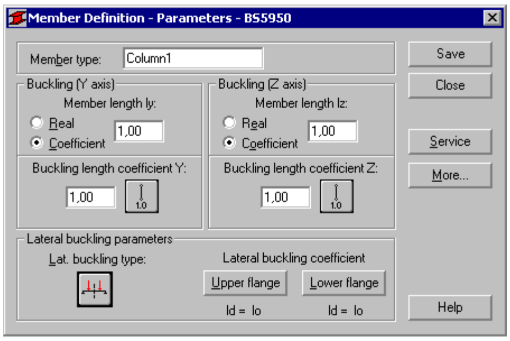
SPECIFICATION:

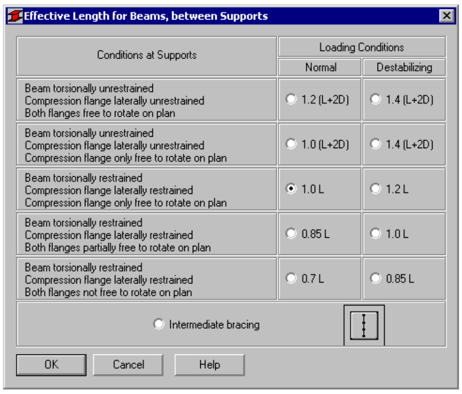


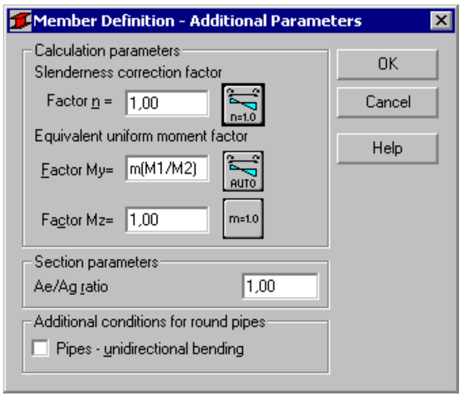
Check the suitability of a 533x210x82 UB in grade 50 steel for use as the column in a portal frame of clear height 5.6 m if the axial compression is 160 kN, the moment at the top of the column is 530 kNm and the base is pinned. The ends of the column are adequately restrained against lateral displacement (i.e. out of the plane) and rotation.
Loading corresponds to compression and major axis moment distributed as shown. Check initially over full height.

SOLUTION:
Define a new type of member. For analysed member pre-defined type of member COLUMN may be initially opened. 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. Then, press *Lat. Buckling* icon and select the first icon (Element loaded symmetrically). Select the icon Lateral buckling coefficient – *Upper flange* that opens *Effective Length of Beams between Supports* dialog box. Choose third radio-button that set the lateral buckling coefficient to 1.0. Repeat the previous procedure for the lower flange. For defining automatic way of equivalent uniform moment factor calculation, press *More* button. Choose the icon for Factor My and select the second icon (Auto) in *Moment factor m* dialog box. Save the newly-created type of member.

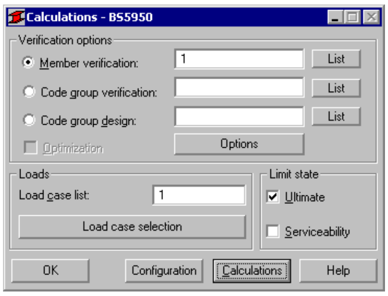




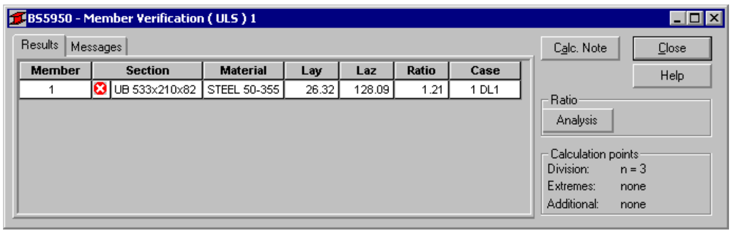




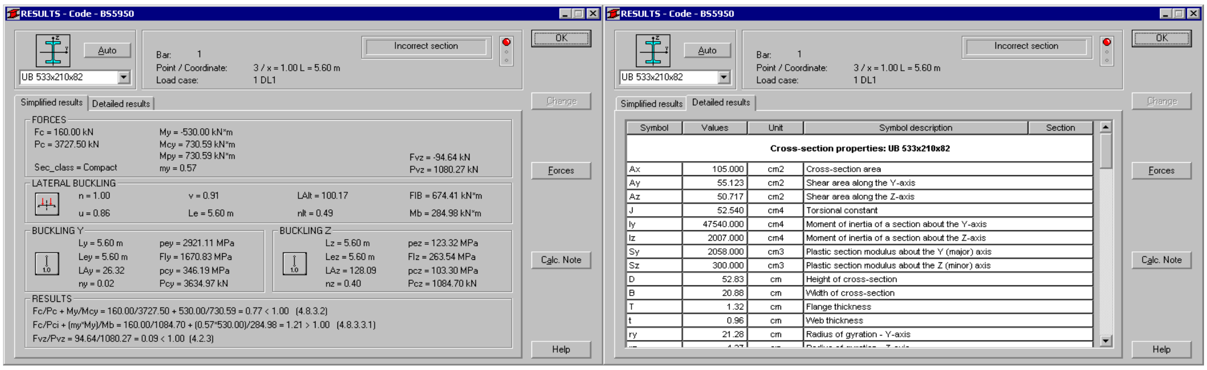
In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analysed). Now, start the calculations by pressing *Calculations* button.



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: *BS 5950: Part1: 1990*

ANALYSIS TYPE: Member Verification

CODE GROUP:

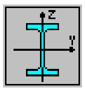
MEMBER: 1 **POINT:** 3 **COORDINATE:** x = 1.00 L = 5.60 m

LOADS:

Governing Load Case: 1 DL1

MATERIAL:

STEEL 50-355 py = 355.00 MPa

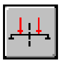


SECTION PARAMETERS: UB 533x210x82

D=52.83 cm			
B=20.88 cm	Ay=55.123 cm2	Az=50.717 cm2	Ax=105.000 cm2
t=0.96 cm	Iy=47540.000 cm4	Iz=2007.000 cm4	J=52.540 cm4
T=1.32 cm	Sy=2058.000 cm3	Sz=300.000 cm3	

INTERNAL FORCES AND CAPACITIES:

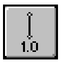
Fc = 160.00 kN	My = -530.00 kN*m	
Pc = 3727.50 kN	Mcy = 730.59 kN*m	
	Mpy = 730.59 kN*m	Fvz = -94.64 kN
Sec_class = Compact	my = 0.57	Pvz = 1080.27 kN



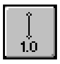
LATERAL BUCKLING PARAMETERS:

Fc = 160.00 kN	v = 0.91	LAlt = 100.17	FIB = 674.41 kN*m
u = 0.86	Le = 5.60 m	nlt = 0.49	Mb = 284.98 kN*m

BUCKLING PARAMETERS:



About Y axis:



About Z axis:

Ly = 5.60 m	pey = 2921.11 MPa	Lz = 5.60 m	pez = 123.32 MPa
Ley = 5.60 m	FIy = 1670.83 MPa	Lez = 5.60 m	FIz = 263.54 MPa
LAy = 26.32	pcy = 346.19 MPa	LAz = 128.09	pcz = 103.30 MPa
ny = 0.02	Pcy = 3634.97 kN	nz = 0.40	Pcz = 1084.70 kN

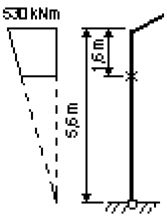
VERIFICATION FORMULAS:

Fc/Pc + My/Mcy = 160.00/3727.50 + 530.00/730.59 = 0.77 < 1.00 (4.8.3.2)

Fc/Pci + (my*My)/Mb = 160.00/1084.70 + (0.57*530.00)/284.98 = 1.21 > 1.00 (4.8.3.3.1)

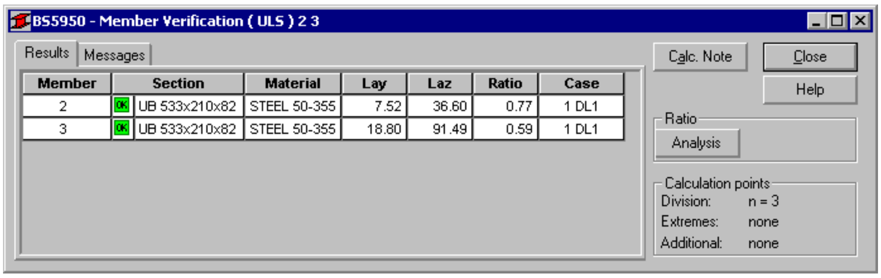
Fvz/Pvz = 94.64/1080.27 = 0.09 < 1.00 (4.2.3)

Incorrect section !!!

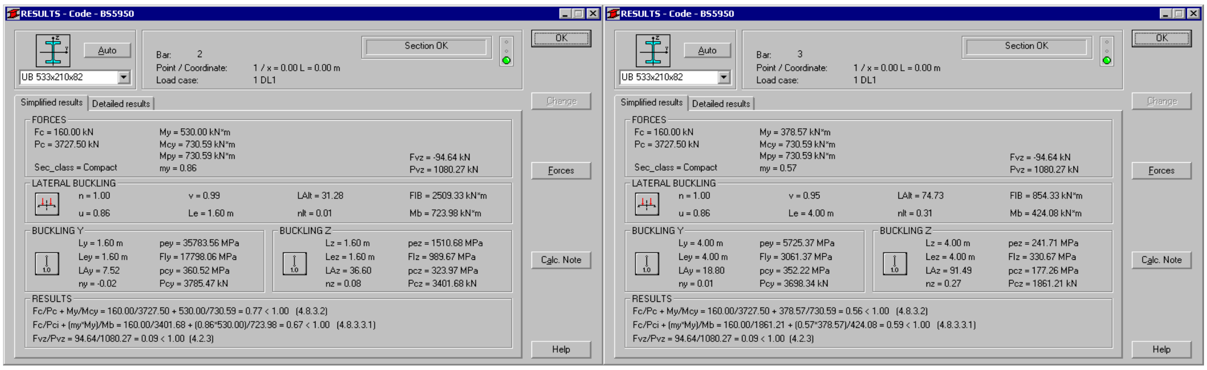


Member has insufficient buckling resistance moment. Increase stability by inserting a brace from a suitable side rail to the compression flange. Estimate suitable location as 1.6 m below the top.

Create new structure consists 2 members: lower one of 4 m length (member 3) and upper one of 1.6 m (member 2). Now analyse each of them separately using previously created type of member **Beam-Column**.



Member		Section	Material	Lay	Laz	Ratio	Case
2	OK	UB 533x210x82	STEEL 50-355	7.52	36.60	0.77	1 DL1
3	OK	UB 533x210x82	STEEL 50-355	18.80	91.49	0.59	1 DL1



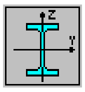
STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

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

LOADS: *Governing Load Case:* 1 DL1

MATERIAL:
STEEL 50-355 py = 355.00 MPa

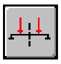


SECTION PARAMETERS: UB 533x210x82

D=52.83 cm			
B=20.88 cm	Ay=55.123 cm2	Az=50.717 cm2	Ax=105.000 cm2
t=0.96 cm	Iy=47540.000 cm4	Iz=2007.000 cm4	J=52.540 cm4
T=1.32 cm	Sy=2058.000 cm3	Sz=300.000 cm3	

INTERNAL FORCES AND CAPACITIES:

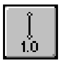
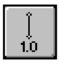
Fc = 160.00 kN	My = 530.00 kN*m	
Pc = 3727.50 kN	Mcy = 730.59 kN*m	
	Mpy = 730.59 kN*m	Fvz = -94.64 kN
Sec_class = Compact	my = 0.86	Pvz = 1080.27 kN



LATERAL BUCKLING PARAMETERS:

Fc = 160.00 kN	v = 0.99	LAlt = 31.28	FIB = 2509.33 kN*m
u = 0.86	Le = 1.60 m	nlt = 0.01	Mb = 723.98 kN*m

BUCKLING PARAMETERS:

 About Y axis:  About Z axis:

Ly = 1.60 m	pey = 35783.56 MPa	Lz = 1.60 m	pez = 1510.68 MPa
Ley = 1.60 m	FIy = 17798.06 MPa	Lez = 1.60 m	FIz = 989.67 MPa
LAy = 7.52	pcy = 360.52 MPa	LAz = 36.60	pcz = 323.97 MPa
ny = -0.02	Pcy = 3785.47 kN	nz = 0.08	Pcz = 3401.68 kN

VERIFICATION FORMULAS:
Fc/Pc + My/Mcy = 160.00/3727.50 + 530.00/730.59 = 0.77 < 1.00 (4.8.3.2)
Fc/Pci + (my*My)/Mb = 160.00/3401.68 + (0.86*530.00)/723.98 = 0.67 < 1.00 (4.8.3.3.1)
Fvz/Pvz = 94.64/1080.27 = 0.09 < 1.00 (4.2.3)

Section OK !!

STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

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

LOADS: *Governing Load Case:* 1 DL1

MATERIAL: STEEL 50-355 py = 355.00 MPa

SECTION PARAMETERS: UB 533x210x82

D=52.83 cm			
B=20.88 cm	Ay=55.123 cm2	Az=50.717 cm2	Ax=105.000 cm2
t=0.96 cm	Iy=47540.000 cm4	Iz=2007.000 cm4	J=52.540 cm4
T=1.32 cm	Sy=2058.000 cm3	Sz=300.000 cm3	

INTERNAL FORCES AND CAPACITIES:

Fc = 160.00 kN	My = 378.57 kN*m	
Pc = 3727.50 kN	Mcy = 730.59 kN*m	
	Mpy = 730.59 kN*m	Fvz = -94.64 kN
Sec_class = Compact	my = 0.57	Pvz = 1080.27 kN

LATERAL BUCKLING PARAMETERS:

Fc = 160.00 kN	v = 0.95	LAlt = 74.73	FIB = 854.33 kN*m
u = 0.86	Le = 4.00 m	nlt = 0.31	Mb = 424.08 kN*m

BUCKLING PARAMETERS:

About Y axis:		About Z axis:	
Ly = 4.00 m	pey = 5725.37 MPa	Lz = 4.00 m	pez = 241.71 MPa
Ley = 4.00 m	FIy = 3061.37 MPa	Lez = 4.00 m	FIz = 330.67 MPa
LAy = 18.80	pcy = 352.22 MPa	LAz = 91.49	pcz = 177.26 MPa
ny = 0.01	Pcy = 3698.34 kN	nz = 0.27	Pcz = 1861.21 kN

VERIFICATION FORMULAS:

Fc/Pc + My/Mcy = 160.00/3727.50 + 378.57/730.59 = 0.56 < 1.00 (4.8.3.2)
Fc/Pci + (my*My)/Mb = 160.00/1861.21 + (0.57*378.57)/424.08 = 0.59 < 1.00 (4.8.3.3.1)
Fvz/Pvz = 94.64/1080.27 = 0.09 < 1.00 (4.2.3)

Section OK !!!

COMPARISON:

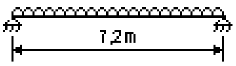
Resistance, interaction expression	Robot	Handbook
1. Compressive strength pcz	177.26	178.00
2. Compression resistance Pcz	1861.21	1851.00
3. Verification formula (4.8.3.3.1)	0.59	0.61

VERIFICATION EXAMPLE 4
- Beam example (Laterally restrained beam)

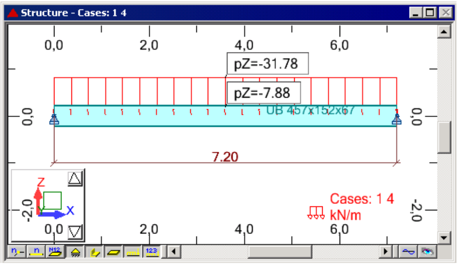
Example taken from STEEL DESIGNERS MANUAL,
Editors: Graham W. Owners and Peter R. Knowles, Fifth edition.

TITLE:
Beam example. Laterally restrained universal beam. See page 437.

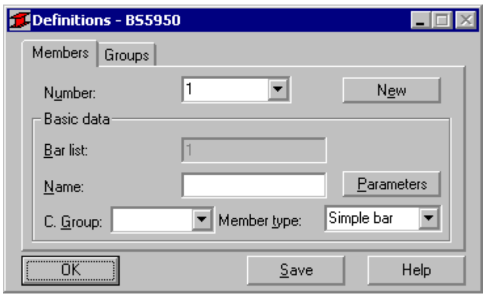
SPECIFICATION:

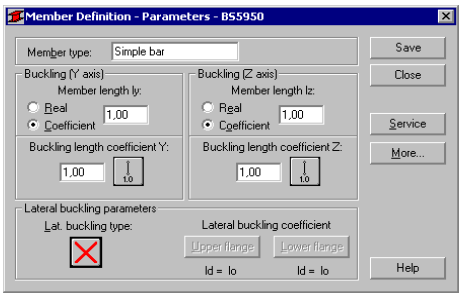


Select a suitable UB section to function as a simply supported beam carrying a 140 mm thick solid concrete slab together with an imposed load of 7.0 kN/m2. Beam span is 7.2 m and beams are spaced at 3,6 intervals. The slab may be assumed capable of providing lateral restraint to the beams top flange.
Due to restraint from slab there is no possibility of lateral-torsional buckling, so design beam for moment and shear capacity. It has been suggested that a UB 457x152x67 section be considered.

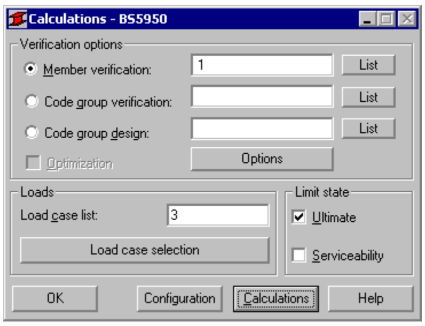


SOLUTION:
Ascribe pre-defined type of member SIMPLE BAR with appropriate set of code parameters for analysed member. It could be done in DEFINITIONS dialog box on the MEMBERS tab.

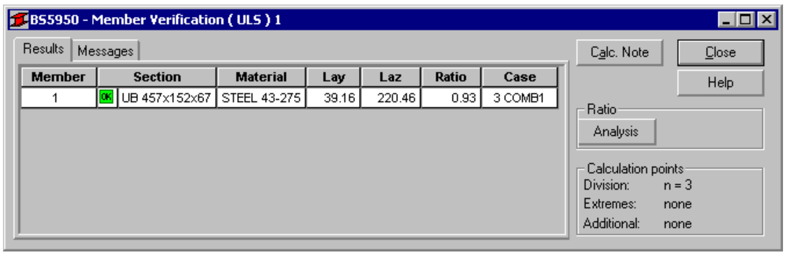




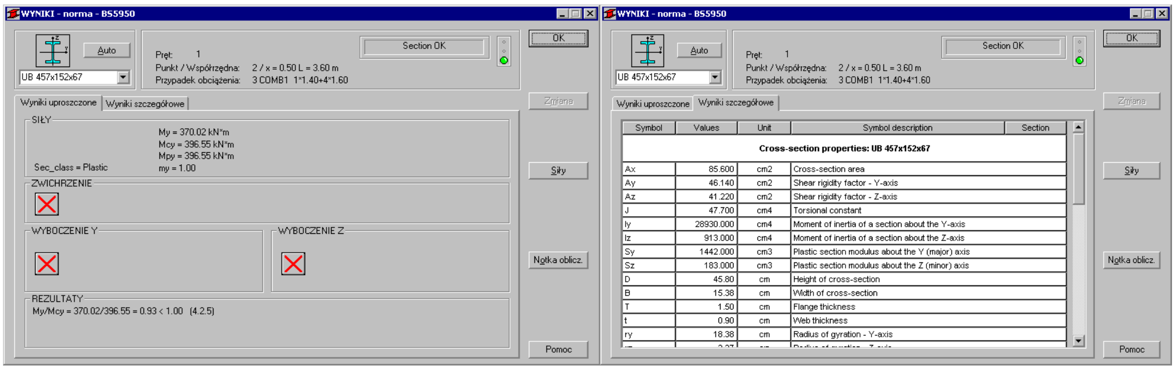
In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit State will be analysed). Now you can start the calculations by pressing *Calculations* button.



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.



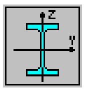
STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 2 **COORDINATE:** x = 0.50 L = 3.60 m

LOADS:
Governing Load Case: 3 COMB1 1*1.40+4*1.60

MATERIAL:
STEEL 43-275 py = 275.00 MPa



SECTION PARAMETERS: UB 457x152x67

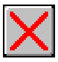
D=45.80 cm			
B=15.38 cm	Ay=46.140 cm2	Az=41.220 cm2	Ax=85.600 cm2
t=0.90 cm	Iy=28930.000 cm4	Iz=913.000 cm4	J=47.700 cm4
T=1.50 cm	Sy=1442.000 cm3	Sz=183.000 cm3	

INTERNAL FORCES AND CAPACITIES:

My = 370.02 kN*m
Mcy = 396.55 kN*m
Mpy = 396.55 kN*m
Sec_class = Plastic my = 1.00

 **LATERAL BUCKLING PARAMETERS:**

BUCKLING PARAMETERS:

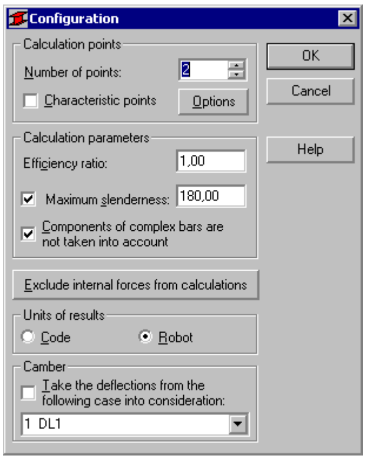
 About Y axis:  About Z axis:

VERIFICATION FORMULAS:

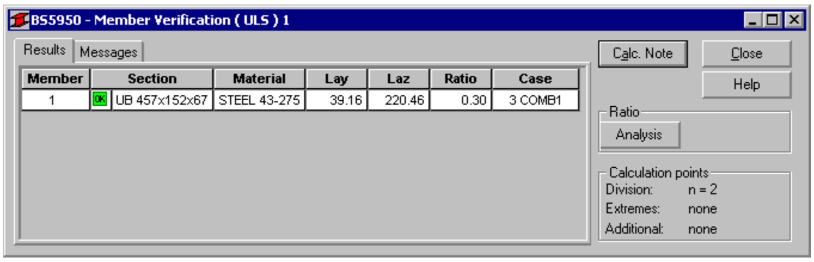
My/Mcy = 370.02/396.55 = 0.93 < 1.00 (4.2.5)

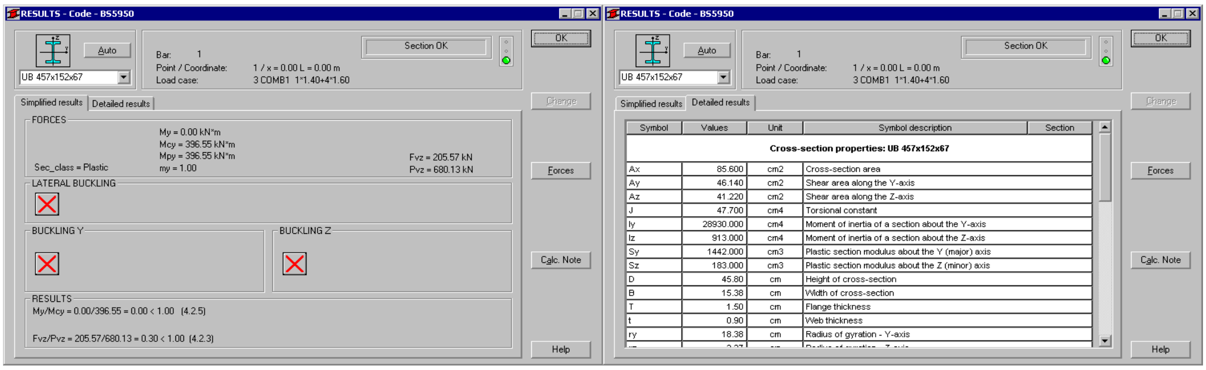
Section OK !!!

To check the shear capacity at the ends of the member set the number of points taken into account to 2. You can do that in CALCULATION | CONFIGURATION dialog box. Then, start calculations again.



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.





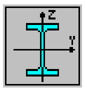
STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

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

LOADS:
Governing Load Case: 3 COMB1 1*1.40+2*1.60

MATERIAL:
STEEL 43-275 py = 275.00 MPa



SECTION PARAMETERS: UB 457x152x67

D=45.80 cm			
B=15.38 cm	Ay=46.140 cm2	Az=41.220 cm2	Ax=85.600 cm2
t=0.90 cm	Iy=28930.000 cm4	Iz=913.000 cm4	J=47.700 cm4
T=1.50 cm	Sy=1442.000 cm3	Sz=183.000 cm3	

INTERNAL FORCES AND CAPACITIES:

	My = 0.00 kN*m	
	Mcy = 396.55 kN*m	
	Mpy = 396.55 kN*m	Fvz = 205.57 kN
Sec_class = Plastic	my = 1.00	Pvz = 680.13 kN

LATERAL BUCKLING PARAMETERS:

BUCKLING PARAMETERS:
About Y axis: About Z axis:

VERIFICATION FORMULAS:
My/Mcy = 0.00/396.55 = 0.00 < 1.00 (4.2.5)
Fvz/Pvz = 205.57/680.13 = 0.30 < 1.00 (4.2.3)

Section OK !!!

COMPARISON:

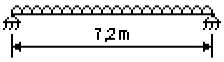
Resistance, interaction expression	Robot	Handbook
1. Moment Mcy	396.55	396.00
2. Design ultimate shear Fvz	205.57	205.00
3. Vertical shear capacity Pvz	680.13	686.00

VERIFICATION EXAMPLE 5
- Beam example 2 (Laterally unrestrained beam)

Example taken from STEEL DESIGNERS MANUAL
Editors: Graham W. Owners and Peter R. Knowles, Fifth edition.

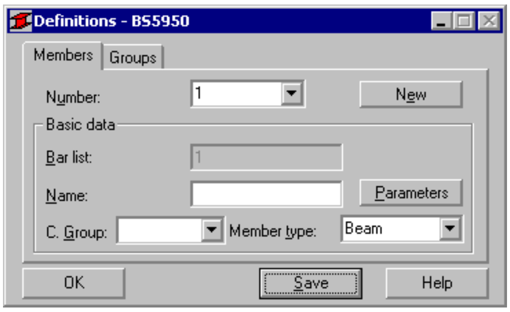
TITLE:
Beam example 2. Laterally unrestrained universal beam. See page 439.

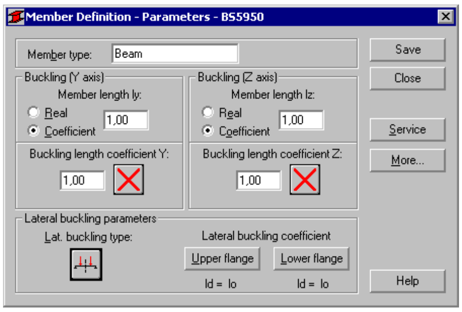
SPECIFICATION:



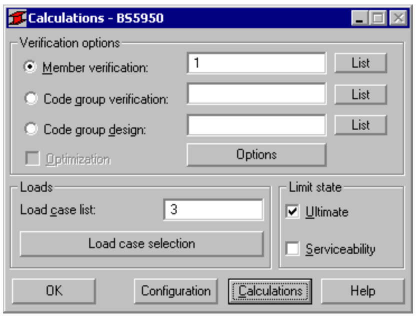
For the same loading and support conditions as in example 4 select a suitable UB assuming that the member must be designed as laterally unrestrained. For simplicity make a safe approximation. Try 610x229x125 UB.

SOLUTION:
Ascribe the pre-defined type of member BEAM with appropriate set of code parameters for the analysed member. It could be done in DEFINITIONS dialog box on the MEMBERS tab.

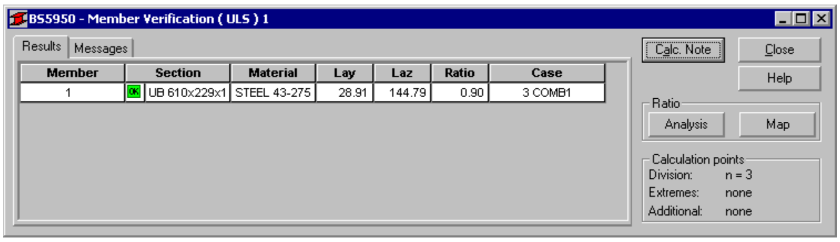




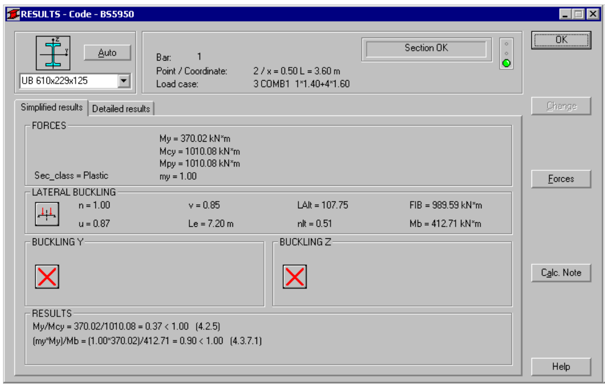
In the CALCULATIONS dialog box set *Member Verification* option for member 1 and switch off *Limit State – Serviceability* (only Ultimate Limit state will be analysed). Now, you can start the calculations by pressing *Calculations* button.

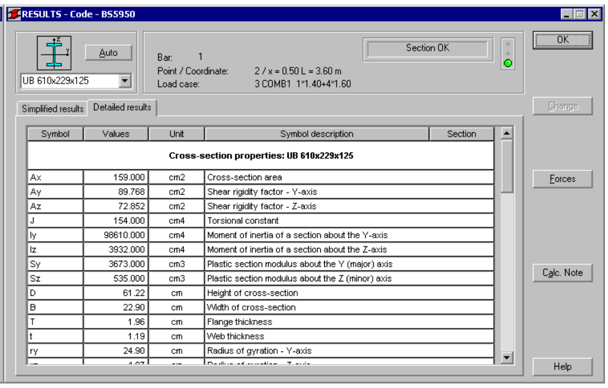


Member Verification dialog box with most significant results data will appear on screen. Pressing the line with results for member 1 opens the RESULTS dialog box with detailed results for the analysed member.



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.





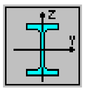
STEEL DESIGN

CODE: *BS 5950: Part1: 1990*
ANALYSIS TYPE: Member Verification

CODE GROUP:
MEMBER: 1 **POINT:** 2 **COORDINATE:** x = 0.50 L = 3.60 m

LOADS:
Governing Load Case: 3 COMB1 1*1.40+4*1.60

MATERIAL:
STEEL 43-275 py = 275.00 MPa

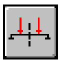


SECTION PARAMETERS: UB 610x229x125

D=61.22 cm			
B=22.90 cm	Ay=89.768 cm2	Az=72.852 cm2	Ax=159.000 cm2
t=1.19 cm	Iy=98610.000 cm4	Iz=3932.000 cm4	J=154.000 cm4
T=1.96 cm	Sy=3673.000 cm3	Sz=535.000 cm3	

INTERNAL FORCES AND CAPACITIES:

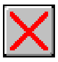
	My = 370.02 kN*m
	Mcy = 1010.08 kN*m
	Mpy = 1010.08 kN*m
Sec_class = Plastic	my = 1.00



LATERAL BUCKLING PARAMETERS:

	v = 0.85	LAlt = 107.75	FIB = 989.59 kN*m
u = 0.87	Le = 7.20 m	nlt = 0.51	Mb = 412.71 kN*m

BUCKLING PARAMETERS:

 About Y axis:  About Z axis:

VERIFICATION FORMULAS:
My/Mcy = 370.02/1010.08 = 0.37 < 1.00 (4.2.5)
(my*My)/Mb = (1.00*370.02)/412.71 = 0.90 < 1.00 (4.3.7.1)

Section OK !!!

COMPARISON:

Resistance, interaction expression	Robot	Handbook
1. Buckling resistance Mb	412.71	427.00

CONCRETE

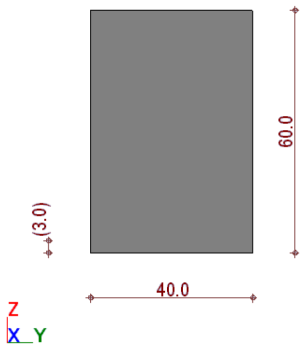
1. BS 9/1/96 – RC columns

VERIFICATION EXAMPLE 1
- 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.

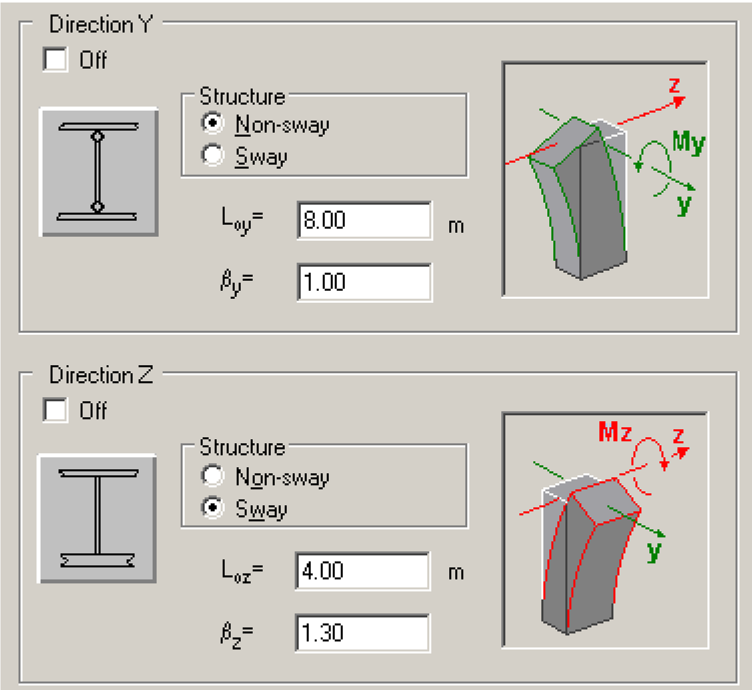
1. SECTION DIMENSIONS



2. MATERIALS

Concrete	: C20	f_{cu} = 20.00 (MPa)
Longitudinal reinforcement	: T	f_y = 460.00 (MPa)
Transversal reinforcement	: R	f_y = 250.00 (MPa)

3. BUCKLING MODEL



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

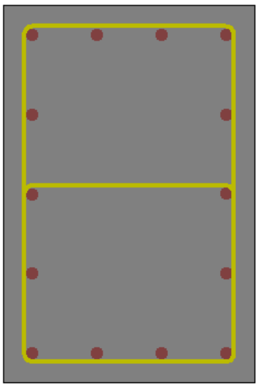
4. LOADS

No.	Case	Nature	Group	N (kN)	MyA (kN*m)	MyB (kN*m)	MyC (kN*m)	MzA (kN*m)	MzB (kN*m)	MzC (kN*m)	γ
1	DL1	dead load	1	400.00	150.00	30.00	102.00	20.00	30.00	50.00	1.40
2	LL1	Live	1	150.00	120.00	30.00	84.00	10.00	20.00	40.00	1.60
*											

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.

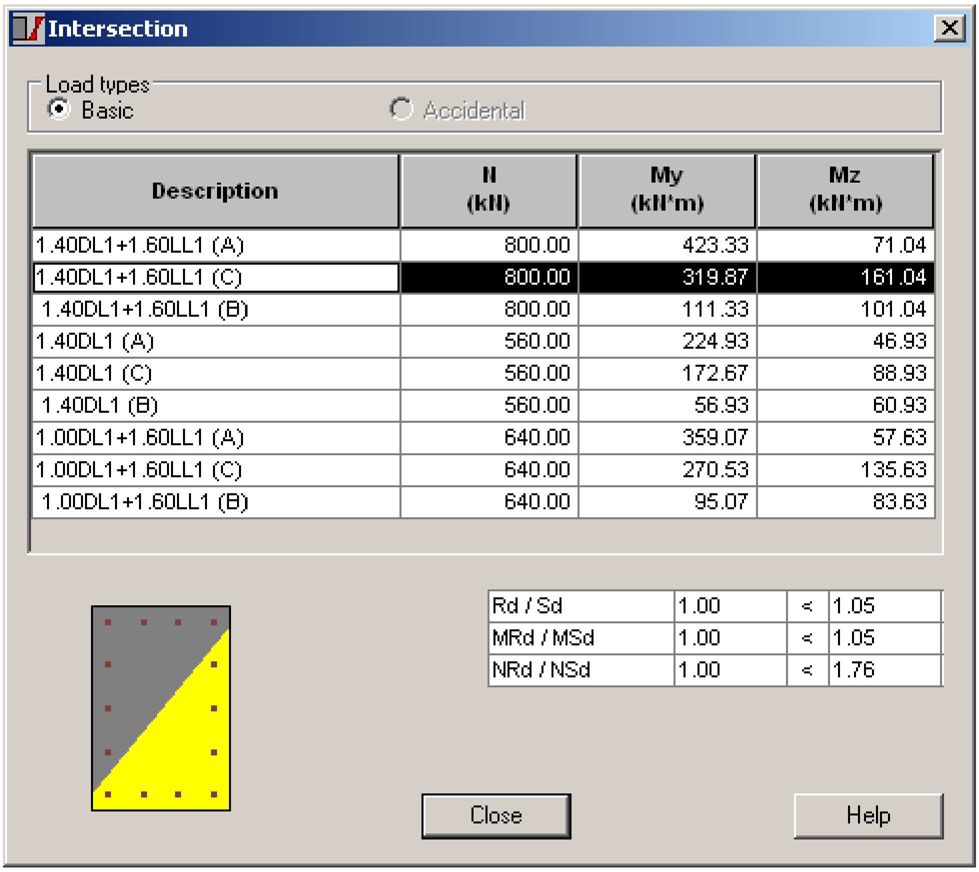
5. CALCULATED REINFORCEMENT:

Program generates the reinforcement 14 ϕ 20.



6. RESULTS OF THE SECTION CALCULATIONS:

The dimensioning combination is 1.4DL1+1.6LL1
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 (marked as (C)).



Description	N (kN)	My (kN*m)	Mz (kN*m)
1.40DL1+1.60LL1 (A)	800.00	423.33	71.04
1.40DL1+1.60LL1 (C)	800.00	319.87	161.04
1.40DL1+1.60LL1 (B)	800.00	111.33	101.04
1.40DL1 (A)	560.00	224.93	46.93
1.40DL1 (C)	560.00	172.67	88.93
1.40DL1 (B)	560.00	56.93	60.93
1.00DL1+1.60LL1 (A)	640.00	359.07	57.63
1.00DL1+1.60LL1 (C)	640.00	270.53	135.63
1.00DL1+1.60LL1 (B)	640.00	95.07	83.63

Rd / Sd	1.00	<	1.05
MRd / MSd	1.00	<	1.05
NRd / NSd	1.00	<	1.76

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

In parallel the other sections (at the ends of the column) are checked for all combinations of loads.
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 (kN)	MyA (kN*m)	MyB (kN*m)	MyC (kN*m)	MzA (kN*m)	MzB (kN*m)	MzC (kN*m)
1	DL1	400	150	30	102	20	30	50*
2	LL1	150	120	30	84	10	20	40*
Dimensioning combination	1.4DL1+1.6LL1	800	402	90	277.2	44	74	134

,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.

Slenderness analysis acc. to 3.8.1.3:
l_{ey} / h = 13.33 < 15 (non-sway for Y direction)
l_{ez} / b = 13.0 > 10 (sway for Z direction)

Since the ratio l_{ez} / b exceeds the limit, the column is found as **slender**.

Y DIRECTION

Calculation of minimum eccentricity *e_{min}* and minimum moment *M_{min}*– 3.8.2.4

$e_{\min} = \min(0.05 \cdot h; 0.02m)$ = 0.02 (m)
$M_{\min} = N \cdot e_{\min}$ = 16.0 (kNm)

Calculation of initial moment *M_i* – eq. 36
For the mid-height section, we have:
$M_i = 0.4 \cdot M_1 + 0.6 \cdot M_2$ = 277.2 (kNm) > $0.4 \cdot M_2$ = 160.8 (kNm)

Calculation of second-order eccentricity *a_u* – eq. 32

$a_u = \beta_a K h$ = 0.053 (m)

$\beta_a = \frac{1}{2000}\left(\frac{l_e}{h}\right)$ = 0.088

$K = \min\left(\frac{N_{uz} - N}{N_{uz} - N_{bal}}; 1\right)$

$N_{uz} = \frac{2}{3}\frac{f_{cu}}{\gamma_c} A_c + \frac{f_y}{\gamma_s} A_{sc} =$ 4060.18 (kN)

A_c = 0.24 (m^2)

A_{sc} = 43.98 (cm^2)

$N_{bal} =$ 1222.64 (kN) – note that this value is calculated in detail for the state equilibrium in a section. Using the approximated code formula one would obtain $N_{bal} =$ 1173.33 (kN)

$K = \left(\frac{N_{uz} - N}{N_{uz} - N_{bal}}\right)$ = - thus, *K* = 1 was assumed

Calculation of second-order moment *M_{add}*

$M_{add} = N \cdot a_u$ = 42.67 (kNm)

NOTE: The second-order effects in Robot are taken into account dependent upon the section and upon the parameter sway/non sway in a following way:

- **in non-sway structures, M_{add} is added for the mid-height section, while 0.5 M_{add} is added for the end sections. Such addition is carried out disregarding the distribution of the first-order moment.**
- **in sway structures, M_{add} is added to each of three sections of column. Such addition is carried out disregarding the distribution of the first-order moment.**

The total moment My :

$M_y = M_i + M_{add} =$ 319.87 (kNm) > 16.00 (kNm) = $M_{\min}$

Z DIRECTION

Calculation of minimum eccentricity e_{min} and minimum moment M_{min} – 3.8.2.4

$e_{\min} = \min(0.05 \cdot b; 0.02m)$ = 0.02 (m)

$M_{\min} = N \cdot e_{\min}$ = 16.0 (kNm)

Calculation of initial moment M_i – eq. 36

For the mid-height section, we have the moment fixed directly by the user:

$M_i =$ 134 (kNm)

Calculation of second-order eccentricity a_u – eq. 32

$a_u = \beta_a K h$ = 0.034 (m)

$$\beta_a = \frac{1}{2000}\left(\frac{l_e}{b}\right) = 0.0845$$

$$K = \min\left(\frac{N_{uz} - N}{N_{uz} - N_{bal}}; 1\right)$$

$$N_{uz} = \frac{2}{3}\frac{f_{cu}}{\gamma_c}A_c + \frac{f_y}{\gamma_s}A_{sc} = 4060.18 \text{ (kN)}$$

A_c = 0.24 (m^2)

A_{sc} = 43.98 (cm^2)

$N_{bal} =$ 1222.64 (kN) – note that this value is calculated in detail for the state equilibrium in a section. Using the approximated code formula one would obtain $N_{bal} =$ 1173.33 (kN)

$K = \left(\frac{N_{uz} - N}{N_{uz} - N_{bal}}\right) =$ - thus, K = 1 was assumed

Calculation of second-order moment M_{add}

$M_{add} = N \cdot a_u$ = 27.04 (kNm)

NOTE: The second-order effects in Robot are taken into account dependent upon the section and upon the parameter sway/non sway in a following way:

- **in non-sway structures, M_{add} is added for the mid-height section, while 0.5 M_{add} is added for the end sections. Such addition is carried out disregarding the distribution of the first-order moment.**
- **in sway structures, M_{add} is added to each of three sections of column. Such addition is carried out disregarding the distribution of the first-order moment.**

The total moment Mz :

$M_z = M_i + M_{add} =$161.04 (kNm) > 16.00 (kNm) = $M_{\min}$

7.3. FINAL RESULT

M_y = 320 (kNm)

M_z = 161 (kNm)

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] British Standard BS 8110: 1985. Structural use of concrete. British Standard Institution, 1985.