
***Chapter 10-N
Steel Structures According to
Indian Standard 800 (2007)***

CivilFEM Theory Manual

Chapter 10-N – Table of Contents

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10-N.1 Scope

For checking steel structures according to Indian Standard IS 800 (2007) in CivilFEM, it is possible to check structures composed by welded or rolled shapes under axial forces, shear forces and bending moments in 3D.

The calculations made by CivilFEM correspond to the recommendations of Indian Standard General Construction in Steel – Code of Practice (Third Revision).

10-N.2 Checking Types

With CivilFEM it is possible to accomplish the following check and analysis types:

- Tension	Section 6.2
- Compression	Section 7.1
- Bending	Section 8.2.1
- Shear force	Section 8.4
- Bending and Shear	Section 9.2
- Lateral Torsional Buckling	Section 8.2.2
- Axial Force with Moments Governed by Material Failure	Section 9.3.1

10-N.3 Valid Element Types

The valid element types supported by CivilFEM are the following 2D and 3D ANSYS link and beam elements:

2D Link	LINK1
3D Link	LINK8
3D Link	LINK10
2D Beam	BEAM3
3D Beam	BEAM4
3D Tapered Unsymmetrical Beam	BEAM44
2D Tapered Elastic Unsymmetrical Beam	BEAM54
2D Plastic Beam	BEAM23
3D Thin-walled Beam	BEAM24
3D Elastic Straight Pipe	PIPE16
3D Plastic Straight Pipe	PIPE20
3D Finite Linear Strain Beam	BEAM188
3D Quadratic Linear Strain Beam	BEAM189

Furthermore, it is possible to check solid sections captured from 2D or 3D models if the cross section is classified as “structural steel”.

10-N.4 Valid Cross-Section Types

Valid cross-sections supported by CivilFEM for checks according to IS 800:2007 are the following:

All rolled shapes included in the program libraries (see the hot rolled shapes library and **~SSECLIB** command).

The following welded beams: double T shapes, U or channel shapes, T shapes, box, equal and unequal legs angles and pipes. (**~SSECDMS** commands).

Structural steel sections defined by plates (command **~SSECPLT**), shapes from solid sections captured from 2D or 3D models in which the transverse cross section is classified as “structural steel”.

CivilFEM considers the above sections as sections composed of plates; for example, an I-section is composed by five plates: four flanges and one web. These cross sections are therefore adapted to the method of analysis of IS 800:2007. Obviously circular sections cannot be decomposed into plates, so these sections are analyzed differently.

10-N.5 Reference Axis

With checks according to IS 800:2007, CivilFEM includes three different coordinate reference systems. All of these systems are right-handed:

1. CivilFEM Reference Axis. (X_{CF} , Y_{CF} , Z_{CF}).
2. Cross-Section Reference Axis. (X_S , Y_S , Z_S).
3. IS 800:2007 Reference Axis. (Code axis), (X_{IS} , Y_{IS} , Z_{IS}).

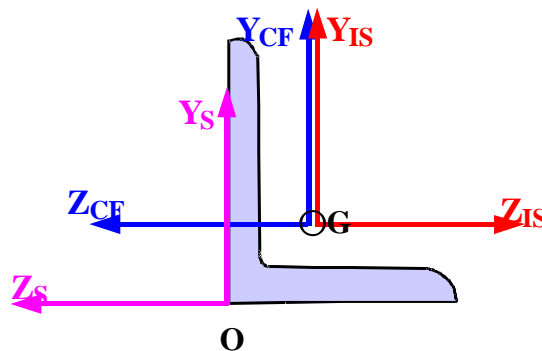


Figure 10-N.5-1 Axis Orientation in Beam Sections

For the IS 800:2007 axis system:

The system origin coincides with the CivilFEM axis origin.

X_{IS} axis coincides with CivilFEM X-axis.

Y_{IS} axis is the relevant axis for bending and its orientation is defined by the user. (`~MEMBPRO` and `~CHKSTL` commands).

Z_{IS} axis is perpendicular to the plane defined by X and Y axis, to ensure a right-handed system.

To define this reference system, the user must indicate which direction of the CivilFEM axis (-Z, -Y, +Z or +Y) coincides with the relevant axis for positive bending. The user may define this reference system with the commands: `~MEMBPRO`, when defining member properties for IS 800:2007 and `~CHKSTL` when checking according to this code. However, in case of any contradiction, the definition considered will be the one established with the `~MEMBPRO` command and the one introduced through the `~CHKSTL` command will be neglected. In conclusion, the code reference system coincides with that of CivilFEM, but it is rotated a multiple of 90 degrees, as demonstrated below.

Table 10-N.5-1

Relevant Axis for Bending in CivilFEM Reference System	Angle of Rotation (in clockwise) of IS 800:2007 Reference System respect to the CivilFEM Reference System
--------------------------------------------------------	-----------------------------------------------------------------------------------------------------------

- Z_{CF}	90 ° (Default value)
- Y_{CF}	180 °
+ Z_{CF}	270 °
+ Y_{CF}	0 °

10-N.6 Data and Results used by CivilFEM

CivilFEM uses the following data and result groups for checks according to IS 800:2007:

Data corresponding to sections: properties and dimensions of gross, net and effective sections; characteristics and dimensions of section plates.

Member properties.

Material properties.

Forces and moments in the section.

Checking results.

10-N.6.1 Sections Data

IS 800:2007 considers the following data set for the section:

- Gross section data
- Net section data
- Effective section data
- Data pertaining to the section and plates class.

Gross section data correspond to the nominal properties of the cross-section.

For the net section, only the area is considered. This area is calculated by subtracting the holes for screws, rivets and other holes from the gross section area. (The area of holes is introduced through the parameter AHOLEs in **~SECMDF** command).

Effective section data and section and plates class data are obtained in the checking process according to the effective width method. For class 4 cross-sections, this method subtracts the non-resistance zones for local buckling. However, for cross-sections of a lower class, the sections are not reduced for local buckling.

The initial required data for the IS 800:2007 module includes the gross section data in user units and the CivilFEM or section axis. The program calculates the effective section data and class data and stores them in CivilFEM's results file, in user units and in the CivilFEM or section axis. The data can be listed and plotted with the **~PLLSSTL** and **~PRSTL** commands.

In the following tables, the section data used in IS 800:2007 are shown:

Table 10-N.6-1 Common data for gross, net and effective sections

Description	Data
Input data:	
1.- Height	H
2.- Web thickness	Tw
3.- Flanges thickness	Tf
4.- Flanges width	B
5.- Distance between flanges	Hi

6.- Radius of fillet (Rolled shapes)	r_1
7.- Toe radius (Rolled shapes)	r_2
8.- Weld throat thickness (Welded shapes)	a
9.- Web free depth	d
Output data	(None)

Table 10-N.6-2 Gross section data

Description	Data	Reference axis
Input data:		
1.- Depth in Y	Tky	CivilFEM
2.- Depth in Z	tkz	CivilFEM
3.- Cross-section area	A	
4.- Moments of inertia for torsion	I_t	CivilFEM
5.- Moments of inertia for bending	I_{yy}, I_{zz}	CivilFEM
6.- Product of inertia	I_{zy}	CivilFEM
7.- Elastic resistant modulus	W_{ely}, W_{elz}	CivilFEM
8.- Plastic resistant modulus	W_{ply}, W_{plz}	CivilFEM
9.- Radius of gyration	i_y, i_z	CivilFEM
10.- Gravity center coordinates	Y_{cdg}, Z_{cdg}	Section
11.- Extreme coordinates of the perimeter	$Y_{min}, Y_{max},$ Z_{min}, Z_{max}	Section
12.- Distance between GC and SC in Y and in Z	Y_{ms}, Z_{ms}	Section
13.- Warping constant	I_w	
14.- Shear resistant areas	Y_{ws}, Z_{ws}	CivilFEM
15.- Torsional resistant modulus	X_{wt}	CivilFEM
16.- Moments of inertia for bending about U, V	I_{uu}, I_{vv}	Principal
17.- Angle Y->U or Z->V	α	CivilFEM
Output data:	(None)	

Table 10-N.6-3 Net section data

Description	Data
Input data:	
1.- Gross section area	A_{gross}
2.- Area of holes	A_{holes}
Output data:	
1.- Net Cross-section area	A_{net}

* The section holes are introduced as a cross section property

The effective section depends on the section geometry and on the forces and moments that are applied to it. Consequently, for each element end, the effective section is calculated.

Table 10-N.6-4 Effective section data

Description	Data	Reference axis
Input data:	(None)	
Output data:		
1.- Cross-section area	Aeff	
2.- Moments of inertia for bending	Iyyeff, Izzeff	CivilFEM
3.- Product of inertia	Izyeff	CivilFEM
4.- Elastic resistant modulus	Wyeff, Wzeff	CivilFEM
5.- Gravity center coordinates	Ygeff, Zgeff	Section
6.- Distance between GC and SC in Y and in Z	Ymseff, Zmseff	Section
7.- Warping constant	Iw	
8.- Shear resistant areas	Yws, Zws	CivilFEM

Table 10-N.6-5 Data referred to the section plates

Description	Data
Input data:	
1.- Plates number	N
2.- Plate type: flange or web (for the relevant axis of bending)	Pltype
3.- Union condition at the ends: free or fixed	Cp1, Cp2
4.- Plate thickness	t
5.- Coordinates of the extreme points of the plate (in Section axis)	Yp1, Yp2, Zp1, Zp2
Output data:	
6.- Reduction factors of the plates at each end	Rho1, Rho2
7.- Plates class	Cl

10-N.6.2 Member Properties

For IS 800:2007 checking, the data set used at member level are shown in the following table. All the data are stored with the section data in user units and in the CivilFEM reference axis. This data is defined as the parameters:

- L, K, KW, C1, C2, C3, CMY, CMZ, CMLT, CFBUCKXY and CFBUCKXZ of **~MEMBPRO** command.

Table 10-N.6-6 Member Properties

Description	EN 1993-1-1:2005
Input data:	
1.- Unbraced length of member (global buckling). Length between lateral restraints (lateral-torsional buckling)	L
2.- Effective length factors	k, kw
3.- Lateral buckling factors, depending on the load and restraint conditions	C1, C2, C3
4.- Equivalent uniform moment factors for flexural buckling	CMy, CMz

Description	EN 1993-1-1:2005
5.- Equivalent uniform moment factors for lateral-torsional buckling	CMLt
6.- Reduction factor for vectorial effects	N/A
7.- Buckling factors for planes XZ and YZ (Effective buckling length for plane XY =L*Cfbuckxy) (Effective buckling length for plane XZ =L*Cfbuckxz)	Cfbuckxy, Cfbuckxz

10-N.6.3 Material Properties

For IS 800:2007 checking, the following material properties are used:

Table 10-N.6-7 Material properties

Description	Properties, symbol
Yield strength	f_y
Ultimate tensile strength	f_u
Partial safety factor for material	Resistance, governed by yielding $\gamma_{m0} = 1.1$
	Resistance of member to buckling $\gamma_{m0} = 1.1$
	Resistance, governed by ultimate stress $\gamma_{m1} = 1.25$
Modulus of elasticity	$E = 200 \text{ kN/mm}^2$
Shear Modulus	$G = \frac{E}{2(1 + \nu)}$
Poisson's ratio	$\nu = 0.3$
Coefficient of linear thermal expansion	$\alpha = 12 \cdot 10^{-6} \text{ } ^\circ\text{C}^{-1}$
Constant ϵ	$\epsilon = \sqrt{\frac{250}{f_y}}$

10-N.6.4 Forces and Moments

The forces applicable for each check are obtained from the CivilFEM results file (.RCV) for the selected load step and substep. CivilFEM will perform all the necessary conversions to conform with the units, axes and criteria of IS 800:2007, including sign-changes according the conventions used in the standard. Internally, CivilFEM performs analyzes using the standard's units and conventions.

The forces and moments considered are shown in the following table. The forces and moments represented below are refer to the code axis (relevant axis for bending Z). All the terms are the used by the code.

Table 10-N.6-8 Forces and moments

External Load	Nd	Vd	Vyd	Vzd	Md	Myd	Mzd	Note
Tension	FX							Tens.+
Compression	-FX							Cmp.+
Bending moment					MY			
Bending moment					MZ			
Shear		FY						
Shear		FZ						
Bending + Shear				FZ		MY		
Bending + Shear			FY				MZ	
Bi-axial bending	-FX					MY	MZ	Cmp.+
Bending and axial force	-FX					MY		Cmp.+
Bending and axial force	-FX						MZ	Cmp.+
Bending + axial + shear	-FX		FY	FZ		MY	MZ	Cmp.+
Buck. resis. Cmp. members	-FX							Cmp.+
Lateral-torsional buckling					MY			
Lateral-torsional buckling					MZ			
Bend. & axial tension buck.	FX					MY		Tens.+
Bend. & axial tension buck.	FX						MZ	Tens.+
Bend. & ax. Comp. buck.	-FX					MY		Cmp.+
Bend. & ax. Comp. buck.	-FX						MZ	Cmp.+

10-N.6.5 Checking Final Results

The ultimate objective is to check if the code conditions for each type of external load are fulfilled.

In general, for every type of external force, the condition required by the code in a section is the following:

$$\frac{N_d}{N_{c,Rd}} + \frac{M_{y,d}}{M_{y,Rd}} + \frac{M_{z,d}}{M_{z,Rd}} \leq 1$$

The numerators of the condition are the forces and moments in the section: the axial force and the bending moments in Y and in Z axis. In some cases, these forces and moments are modified by correction factors that depend on the type of external load as well as the presence of shear forces.

The denominators include the design resistances to each of the forces and moments in the cross-section. These terms are calculated in a specific way for each type of external load and for each cross-section class. Additionally, the section class depends on the cross-section type and the internal forces and moments.

CivilFEM stores the results for each element end in an alternative in the CivilFEM results file (.RCV). These results can be retrieved with the corresponding alternative number using the command **~CFSET**.

The available results data for each checking type are described in the tables included in the following sections corresponding to the different checking types executed by the program.

10-N.7 Checking Process

The checking process includes the evaluation of the following expression:

$$\frac{N_{Ed}}{N_{c,Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1$$

Evaluation steps:

1. Read the checking type requested by the user.
2. Default checking type: Bending, shear and axial force.
3. Read the CivilFEM axis to be considered as the relevant axis for bending so that it coincides with the Y axis of IS 800:2007. In CivilFEM, by default, the principle bending axis that coincides with the +Y axis of IS 800:2007 is the -Z.
4. The following operations are necessary for each selected element:
 - a) Obtain material properties of the element stored in CivilFEM database and calculate the rest of the properties needed for checking:
Properties obtained from CivilFEM database:

Calculated properties:

Epsilon, material coefficient:

$$\varepsilon = \sqrt{235/f_y(\text{th})} \quad (f_y \text{ in N/mm}^2)$$

- b) Obtain the cross-section data corresponding to the element.
- c) Initialize values of the effective cross-section.
- d) Initialize reduction factors of section plates and the rest of plate parameters necessary for obtaining the plate class.
- e) If necessary for the type of check (check for buckling), calculate the critical forces and moments of the section for buckling: elastic critical forces for the XY and XZ planes and elastic critical moment for lateral-torsional buckling. (See section: Calculation of critical forces and moments).
- f) Obtain internal forces and moments (T_d , P_d , $V_{y,d}$, $V_{z,d}$, $M_{x,d}$, $M_{y,d}$, $M_{z,d}$ within the section.
- g) Specific section checking according to the type of external load. The specific check includes:
 1. If necessary, selecting the forces and moments considered for the determination of the section class and used for the checking process.
 2. Obtaining the cross-section class and calculating the effective section properties (See Section: General Processing of Sections).
 3. Checking the cross-section according to the external load and its class by calculating the following criteria: Crt_TOT , Crt_N , Crt_Mx and Crt_My .
- h) Recording the results.

10-N.7.1 General Processing of Sections. Section Class and Reduction Factors Calculation.

Sections, according to IS 800:2007, are made up by plates. These plates can be classified according to:

5. Plate function: webs and flanges in Y and Z axis, according to the considered relevant axis of bending.
6. Plate union condition: internal plates or outstand plates.

For sections included in the program libraries, the information above is defined for each plate. CivilFEM classifies plates as flanges or webs according to their axis and provides the plate union condition for each end. Ends can be classified as fixed or free (a fixed end is connected to another plate and free end is not).

For checking the structure for safety, IS 800:2007 classifies sections as one of four possible classes:

Class 1 (Plastic)	Cross-sections, which can develop plastic hinges and have the rotation capacity required for failure of the structure by formation of plastic mechanism.
Class 2 (Compact)	Cross-sections, which can develop plastic moment of resistance, but have inadequate plastic hinge rotation capacity for formation of plastic mechanism, due to local buckling.
Class 3 (Semi-Compact)	Cross-sections, in which the extreme fiber in compression can reach yield stress, but cannot develop the plastic moment of resistance, due to local buckling.
Class 4 (Slender)	Cross-sections in which the elements buckle locally even before reaching yield stress.

The cross-section class is the highest (least favorable) class of all of its elements: flanges and webs (plates). First, the class of each plate is determined according to the limits of IS 800:2007. The plate class depends on the following:

1. The geometric width to thickness ratio with the plate width properly corrected according to the plate and shape type.

$$\text{GeomRat} = \text{Corrected_Width} / \text{thickness}$$

The width correction consists of subtracting the zone that does not contribute to buckling resistance in the fixed ends. This zone depends on the shape type of the section. Usually, the radii of the fillet in hot rolled shapes or the weld throats in welded shapes determine the deduction zone. The values of the corrected width that CivilFEM uses for each shape type include:

- **Welded Shapes:**

Double T section:

Internal webs or flanges:

Corrected width = d

d Web free depth

Outstand flanges:

$$\text{Corrected width} = \frac{B}{2} - \frac{T_w}{2} - r_1$$

Where:

B	Flanges width
T_w	Web thickness
r_1	Radius of fillet

T section:

Internal webs or flanges:

$$\text{Corrected width} = d$$

Outstand flanges:

$$\text{Corrected width} = \frac{B}{2}$$

C section:

Internal webs or flanges:

$$\text{Corrected width} = d$$

Outstand flanges:

$$\text{Corrected width} = B - T_w - r_1$$

L section:

$$\text{Corrected width} = \sqrt{I_1^2 + I_2^2}$$

I_1, I_2 Angle flange width

Box section:

Internal webs:

$$\text{Corrected width} = H$$

H Height

Internal flanges:

$$\text{Corrected width} = B = 2 \cdot T_w$$

T_w Web thickness

Circular hollow section

$$\text{Corrected width} = H$$

• **Rolled Shapes:**

Double T section:

Internal webs or flanges:

Corrected width = d

d Web free depth

Outstand flanges:

Corrected width = $\frac{B}{2}$

B Flanges width

T Section:

Internal webs or flanges:

Corrected width = d

Outstand flanges:

Corrected width = $\frac{B}{2}$

C Section:

Internal webs or flanges:

Corrected width = d

Outstand flanges:

Corrected width = B

L Section:

Corrected width = $\sqrt{I_1^2 + I_2^2}$

I_1, I_2 Angle flange width

Box section:

Internal webs:

Corrected width = d

Internal flanges:

Corrected width = $B - 3 \cdot T_f$

T_f Flanges thickness

Pipe section:

Corrected width = H

2. The limit listed below for width to thickness ratio. This limit depends on the material parameter ε and the normal stress distribution in the plate section. The latter value is given by the following parameters: α , Ψ , and k_0 , and the plate type, internal or outstand; the outstand case depends on if the free end is under tension or compression.

Limit (class) = $f(\varepsilon, \alpha, \Psi, k_0)$

$\varepsilon = \sqrt{235/f_y}$ (f_y in N/mm²)

where:

α Compressed length / total length

ψ	σ_2/σ_1
k_0	Buckling factor
σ_1	The higher stress in the plate ends.
σ_2	The lower stress in the plate ends.

A linear stress distribution on the plate is assumed.

The procedure to determine the section class is as follows:

1. Obtain stresses at first plate ends from the stresses applied on the section, properly filtered according to the check type requested by the user.
2. Calculate the parameters: α , Ψ and k_0

For internal plates:

$0 > \Psi > -1$	$k_0 = 7.81 - 6.29 \cdot \Psi + 9.78 \cdot \Psi^2$
$-1 \geq \Psi > -2$	$k_0 = 5.98 \cdot (1 - \Psi)^2$
$\Psi \leq -2$	$k_0 = \text{infinite}$

For outstand plates with an absolute value of the stress at the free end greater than the corresponding value at the fixed end:

For $1 \geq \Psi \geq -1$

$$k_0 = 0.57 - 0.21 \cdot \Psi + 0.07 \cdot \Psi^2$$

For $-1 > \Psi$

$$k_0 = \text{infinite}$$

For outstand plates with an absolute value of the stress at the free end lower than the corresponding value at the fixed end:

For $1 \geq \Psi \geq 0$

$$k_0 = \frac{0.578}{\Psi + 0.34}$$

For $0 > \Psi \geq -1$

$$k_0 = 1.7 - 5 \cdot \Psi + 17.1 \cdot \Psi^2$$

For $-1 > \Psi$

$$k_0 = \text{infinite}$$

Cases in which $k_0 = \text{infinite}$ are not included in IS 800:2007. With these cases, the plate is considered to be practically in tension and it will not be necessary to determine the class. These cases have been included in the program to avoid errors, and the value $k_0 = \text{infinite}$ has been adopted because the resultant plate class is 1 and the plate reduction factor is $\rho = 1$ (the same values as if the whole plate was in tension). The reduction factor is used later in the effective section calculation.

3. Obtain the limiting proportions as functions of: α , Ψ and k_0 and the plate characteristics (internal, outstand: free end in compression or tension).

Internal plates:

$$\text{Limit}(1) = 396 \varepsilon / (13\alpha - 1) \quad \text{for } \alpha < 0.5$$

$$\text{Limit}(1) = 36 \varepsilon / \alpha \quad \text{for } \alpha < 0.5$$

$$\text{Limit}(2) = 456 \varepsilon / (13\alpha - 1) \quad \text{for } \alpha \geq 0.5$$

$$\text{Limit}(2) = 41.5 \varepsilon / \alpha \quad \text{for } \alpha < 0.5$$

$$\text{Limit}(3) = 42 \varepsilon / (0.67 + 0.33\Psi) \quad \text{for } \Psi > -1$$

$$\text{Limit}(3) = 62 \varepsilon (1 - \Psi) \sqrt{-\Psi} \quad \text{for } \Psi \leq -1$$

Outstand plates, free end in compression:

$$\text{Limit}(1) = 9 \varepsilon / \alpha$$

$$\text{Limit}(2) = 10 \varepsilon / \alpha$$

$$\text{Limit}(3) = 21 \varepsilon / \sqrt{k_0}$$

Outstand plates, free end in tension:

$$\text{Limit}(1) = \frac{9 \varepsilon}{\alpha \sqrt{\alpha}}$$

$$\text{Limit}(2) = \frac{10 \varepsilon}{\alpha \sqrt{\alpha}}$$

$$\text{Limit}(3) = 21 \varepsilon / \sqrt{k_0}$$

Above is the general equation used by the program to obtain the limiting proportions for determining plate classes. In addition, plates of IS 800:2007 may be checked according to special cases.

For example:

In sections totally compressed:

$$\alpha = 1; \quad \Psi = 1 \text{ for all plates}$$

In sections under pure bending:

$$\alpha = 0.5; \quad \Psi = -1 \text{ for the web}$$

$$\alpha = 1; \quad \Psi = 1 \text{ for compressed flanges}$$

4. Obtain the plate class:

$$\text{If } \text{GeomRat} < \text{Limit}(1) \text{ Plate Class} = 1$$

- If $\text{Limit}(1) \leq \text{GeomRat} < \text{Limit}(2)$ Plate Class = 2
 If $\text{Limit}(2) \leq \text{GeomRat} < \text{Limit}(3)$ Plate Class = 3
 If $\text{Limit}(3) \leq \text{GeomRat}$ Plate Class = 4

Repeat these steps (1,2,3,4) for each section plate.

5. Assign of the highest class of the plates to the entire section.
 In tubular sections, the section class is directly determined as if it were a unique plate, with GeomRat and the Limits calculated as follows:
6. $\text{GeomRat} = \text{outer diameter} / \text{thickness}$.
 $\text{Limit}(1) = 50 \varepsilon^2$
 $\text{Limit}(2) = 70 \varepsilon^2$
 $\text{Limit}(3) = 90 \varepsilon^2$

For class 4 sections, the section resistance is reduced, using the effective width method.

For each section plate, the effective lengths at both ends of the plate and the reduction factors ρ_1 and ρ_2 are calculated. These factors relate the length of the effective zone at each plate end to its width.

$$\text{Effective_length_end1} = \text{plate_width} * \rho_1$$

$$\text{Effective_length_end 2} = \text{plate_width} * \rho_2$$

The following formula from IS 800:2007 has been implemented for this process:

$$\Psi = \sigma_2 \sigma_1$$

1. Internal plates:

For $0 \leq \Psi \leq 1$ (Both ends compressed)

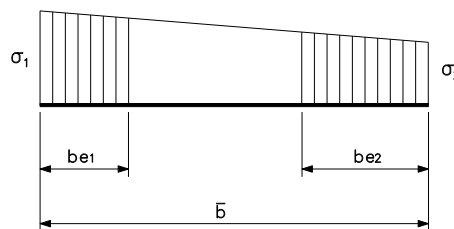


Figure 10-N.7-1 Internal plates

$$b_{\text{eff}} = \rho \bar{b}$$

$$b_{e1} = 2b_{\text{eff}} / (5 - \Psi)$$

$$b_{e2} = b_{\text{eff}} - b_{e1}$$

$$\rho_1 = \frac{b_{e1}}{\text{plate_width}}$$

$$\rho_2 = \frac{b_{e2}}{\text{plate_width}}$$

\bar{b} = corrected plate width

plate_width = real plate width

For $\Psi < 0$ (end 1 in compression and end 2 in tension)

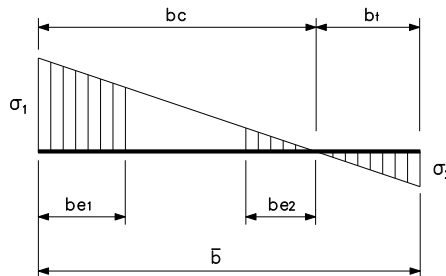


Figure 10-N.7-2

$$b_{\text{eff}} = \rho b_c = \rho \bar{b} / (1 - \Psi)$$

$$b_{e1} = 0.4 b_{\text{eff}}$$

$$b_{e2} = 0.6 b_{\text{eff}}$$

$$\rho_1 = \frac{b_{e1}}{\text{plate_width}}$$

$$\rho_2 = \frac{b_{e2} + b_t}{\text{plate_width}}$$

2. Outstand plates:

For $0 \leq \Psi \leq 1$ (Both ends in compression: end 1 fixed, end 2 free)

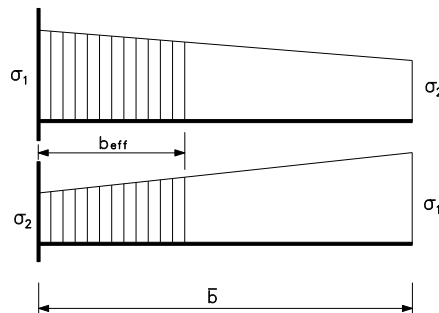


Figure 10-N.7-3

$$b_{\text{eff}} = \rho \bar{b}$$

$$\rho_1 = \frac{b_{e1}}{\text{plate_width}}$$

$$\rho_2 = 0$$

For $\Psi < 0$ (end 1 fixed and in tension, end 2 free and in compression)

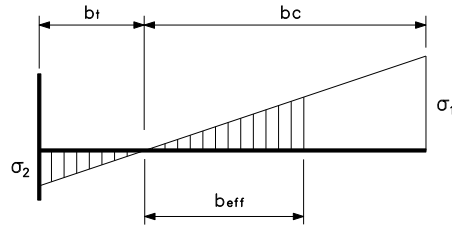


Figure 10-N.7-4

$$b_{\text{eff}} = \rho b_c = \rho c / (1 - \Psi)$$

$$\rho_1 = \frac{b_{\text{eff}} + b_t}{\text{plate_width}}$$

$$\rho_2 = 0$$

For $\Psi < 0$ (end 1 fixed and in compression, end 2 free and in tension)

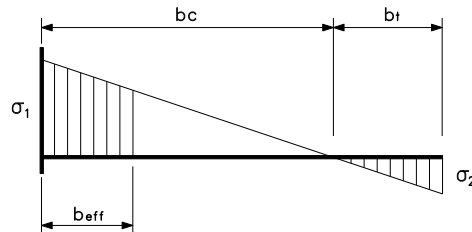


Figure 10-N.7-5

$$\zeta b_{\text{eff}} = \rho b_c = \rho c / (1 - \Psi)$$

$$\rho_1 = \frac{b_{\text{eff}}}{\text{plate_width}}$$

$$\rho_2 = \frac{b_t}{\text{plate_width}}$$

If end 2 is the fixed end, the values ρ_1 and ρ_2 are switched.

The global reduction factor ρ is obtained by as follows:

For internal compression elements

For $\bar{\lambda}_p > 0.673$

$$\rho = \frac{\bar{\lambda}_p - 0.055(3 + \Psi)}{\bar{\lambda}_p^2}$$

For $\bar{\lambda}_p \leq 0.673$

$$\rho = 1$$

For outstands compression elements:

For $\bar{\lambda}_p > 0.748$

$$\rho = \frac{\bar{\lambda}_p - 0.188}{\bar{\lambda}_p^2}$$

For $\bar{\lambda}_p \leq 0.748$

$$\rho = 1$$

$\bar{\lambda}_p$ is defined as the plate slenderness given by:

$$\bar{\lambda}_p = \frac{\bar{b}/t}{28.4\varepsilon\sqrt{k_0}}$$

where:

\bar{b} = corrected plate width

t = relevant thickness

ε = material parameter

k_0 = buckling factor

To determine effective section properties, three steps are followed:

1. *Effective widths of flanges* are calculated from factors α and Ψ ; these factors are determined from the gross section properties. As a result, an intermediate section is obtained with reductions taken in the flanges only.
2. The resultant section properties are obtained and factors α and Ψ are calculated again.
3. *Effective widths of webs* are calculated so that the finalized effective section is determined. Finally, the section properties are recalculated once more.

The recalculated section properties are included in the effective section data table. Checking can be accomplished with the gross, net or effective section properties, according to the section class and checking type.

Each checking type follows a specific procedure that will be explained in the following sections.

10-N.7.2 Checking of Members in Axial Tension

Corresponds to chapter 6 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$T = FX$ Design value of the axial force (positive if tensile, element not processed if compressive).

2. Class determination.
3. Criteria calculation.

For members under axial tension, the general criterion Crt_TOT is checked at each section.

$$T \leq T_d \rightarrow Crt_TOT = \frac{T}{T_d} \leq 1$$

Where T_d is the design strength of the member.

If we only take into account the design strength due to yielding of gross section (article 6.2, IS800:2007):

$$T_d = T_{dg} = A_g f_y / \gamma_{m0}$$

If we take into account the design strength in tension of a plate, as governed by rupture of net cross-sectional area:

$$T_d = T_{dn} = 0.9 A_n f_u / \gamma_{m1}$$

A_n is the net cross-sectional area and it will be calculated as $A_g - A_{holes}$

A_{holes} should be included by the user according to the IS 800:2007

$$T_d = \min(T_{dg}, T_{dn})$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table:

Table 10-N.7-1 Checking of Members in Axial Tension

Result	Concepts	Description
T	T	Tension Force.
TD	Td	Design strength of the member.
TDG	Tdg	Design strength due to yielding of gross section.
TDN	Tdn	Design strength in tension of a plate, as governed by rupture of net cross-sectional area.
CRT_TOT	T/T _d	Global criterion.

10-N.7.3 Checking of Members in Axial Compression

Corresponds to chapter 7 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$N_d = FX$ Design value of the axial force (positive if compressive, element not processed if tensile). Represented as P_d in IS-800-2007.

2. Class definition and effective section properties calculation.

For this check type, the section class is always 1 and the considered section is the gross or net section.

3. Criteria calculation.

For members in axial compression, the general criterion Crt_TOT is checked at each section. This criterion coincides with the axial criterion Crt_N :

$$N_{Sd} \leq N_{c,Rd} \rightarrow Crt_TOT = Crt_N = \frac{N_{Sd}}{N_{c,Rd}} \leq 1$$

where $N_{c,Rd}$ is the design compression resistance of the cross-section

Class 1,2 or 3 cross-sections:

$N_{c,Rd} = Af_y/Y_{M0}$ design plastic resistance of the gross section

Class 4 cross sections:

$$N_{c,Rd} = A_{eff}f_y/Y_{M0}$$

4. Output results written in the CivilFEM results file (.RCV) as an alternative.

Checking results: criteria and variables are described at the following table.

Table 10-N.7-2 Checking of Members in Axial Compression

Result	Concepts	Description
NED	N_{Ed}	Design axial force
NCRD	$N_{c,Rd}$	Design compression strength of the cross-section.
CRT_N	$N_d/N_{c,Rd}$	Axial criterion.
CRT_TOT	$N_d/N_{c,Rd}$	IS 800:2007 global criterion.
CLASS		Section Class.
AREA	A, A_{eff}	Area of the section (Gross or Effective).

10-N.7.4 Checking of Members under Bending Moment

Corresponds to chapter 8 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$M_d = My \text{ or } Mz$ Design value of the bending moment along the relevant axis for bending. Represented as M_d in IS-800-2007.

2. Class definition and effective section properties calculation.

The section class is determined by the general processing of the section with

the previously selected forces and moments if the selected option is partial or with all the forces and moments if the selected option is full. The entire calculation process is accomplished with the gross section properties.

3. Criteria calculation.

For members subjected to a bending moment in the absence of shear force, the following condition is checked at each section:

$$|M_d| \leq M_{c,Rd} \rightarrow \text{Crt_TOT} = \text{Crt_My} = \left| \frac{M_d}{M_{c,Rd}} \right| \leq 1$$

where:

M_d = design value of the bending moment

$M_{c,Rd}$ = design moment resistance of the cross-section

Class 1 or 2 cross-sections:

$$M_{c,Rd} = W_{pl} \cdot f_y / Y_{M0}$$

Class 3 cross sections:

$$M_{c,Rd} = W_{el} \cdot f_y / Y_{M0}$$

Class 4 cross sections:

$$M_{c,Rd} = E_{eff} \cdot f_y / Y_{M0}$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-3 Checking of Members under Bending Moment

Result	Concepts	Description
MED	M_{Ed}	Design value of the bending moment.
MCRD	$M_{c,Rd}$	Design moment resistance of the cross-section.
CRT_M	$M_d/M_{c,Rd}$	Bending criterion.
CRT_TOT	$M_d/M_{c,Rd}$	IS 800:2007 global criterion.
CLASS		Section Class.
W	W_{el}, W_{pl}, W_{eff}	Used section modulus (Elastic, Plastic or Effective).

10-N.7.5 Checking of Members under Shear Force

Corresponds to chapter 8.4 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$$V_d = F_z \text{ or } F_y \quad \text{Design value of the shear force perpendicular to the relevant axis of bending.}$$

2. Class definition and effective section properties calculation.

For this checking type, the section class is always 1 and the effective section is the gross section.

3. Criteria calculation.

With members under shear force, the following condition is checked at each section:

$$|V_d| \leq V_{Pl.Rd} \rightarrow CRT_TOT = CrT_S = \left| \frac{V_d}{V_{Pl.Rd}} \right| \leq 1$$

where:

V_d design value of the shear force

$V_{Pl.Rd}$ design plastic shear resistance: $V_{Pl.Rd} = A_v(f_y/\sqrt{3})/Y_{M0}$

A_v shear area, obtained subtracting from the gross area the summation of the flanges areas: $A_v = A - \sum Flanges_Area$

Modifications to the previous computation of A_v are as follows:

- a. Rolled I and H sections, load parallel to web:

$$A_v = A_v + (t_w + 2r)t_f$$

- b. Rolled channel sections, load parallel to web:

$$A_v = A_v + (t_w + r)t_f$$

EN 1993-1-1:2005 specifies additional cases for the calculation of A_v :

- Rolled I and H sections with load parallel to web:

$$A_v = A_v + (t_w + 2r)t_f \quad \text{but not less than } \eta h_w t_w$$

- Rolled T shaped sections with load parallel to web:

$$A_v = 0.9 \cdot (A - b \cdot t_f)$$

Where:

η $\eta = 1.2$ for steels with $f_y = 460$ MPa

$\eta = 1.0$ for steels with $f_y > 460$ MPa

h_w Web depth

t_w Web thickness

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-4 Checking of Members under Shear Force

Result	Concepts	Description
VED	V_{Ed}	Design value of the shear force.
VPLRD	$V_{pl.Rd}$	Design plastic shear resistance.
CRT_S	$V_d/V_{pl.Rd}$	Shear criterion.

CRT_TOT	$V_d/V_{pl.Rd}$	IS 800:2007 global criterion.
CLASS		Section Class.
S_AREA	A_v	Shear area.

10-N.7.6 Checking of Members under Bending Moment and Shear Force

Corresponds to chapter 9.2 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$V_d = Fz \text{ or } Fy$ Design value of the shear force perpendicular to the relevant axis of bending.

$M_d = My \text{ or } Mz$ Design value of the bending moment along the relevant axis of bending.

2. Class definition and effective section properties calculation.

The section class is determined by the general processing of the sections with the previously selected forces and moments if the selected option is partial or with all the forces and moments if the selected option is full. The entire calculation is accomplished with gross section properties.

3. Criteria calculation.

For members subjected to bending moment and shear force, the following condition is checked at each section:

$$|M_d| \leq M_{V.Rd} \rightarrow \text{Crt_TOT} = \text{Crt_BS} = \left| \frac{M_d}{M_{V.Rd}} \right| \leq 1$$

Where:

$M_{V.Rd}$ = design resistance moment of the cross-section, reduced by the presence of shear.

The reduction for shear is applied if the design value of the shear force exceeds 50% of the design plastic shear resistance of the cross-section; written explicitly as:

$$V_d > 0.5 V_{pl.Rd}$$

The design resistance moment is obtained as follows:

a) For double T cross-sections with equal flanges, bending about the major axis:

$$M_{V.Rd} = \left(W_{pl} - \frac{\rho A_v^2}{4t_w} \right) f_y / Y_{M0}$$

$$\rho = \left(\frac{2V_d}{V_{pl.Rd}} - 1 \right)^2$$

$$A_w = h_w t_w$$

a) For other cases the yield strength is reduced as follows:

$$f_y = f_y (1 - \rho)$$

Note: This reduction of the yield strength f_y is applied to the entire section. IS 800:2007 only requires the reduction to be applied to the shear area, and therefore, it is a conservative simplification.

For both cases, $M_{V.Rd}$ is the smaller value of either $M_{V.Rd}$ or $M_{C.Rd}$.

$M_{C.Rd}$ is the design moment resistance of the cross-section, calculated according to the class.

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-5 Checking of Members under Bending Moment and Shear Force

Result	Concepts	Description
MED	M_{Ed}	Design value of the bending moment.
VED	V_{Ed}	Design value of the shear force.
MVRD	$M_{v.Rd}$	Reduced design resistance moment of the cross-section.
CRT_BS	$M_d/M_{v.Rd}$	Bending and Shear criterion.
CRT_TOT	$M_d/M_{v.Rd}$	IS 800:2007 global criterion.
CLASS		Section Class.
S_AREA	A_v	Shear area.
W	W_{el}, W_{pl}, W_{eff}	Used section modulus (Elastic, Plastic or Effective).
VPLRD	$V_{pl.Rd}$	Design plastic shear resistance.
RHO	ρ	Reduction factor.

10-N.7.7 Checking of Members under Bending Moment + Axial Force and Bi-axial Bending + Axial Force

Corresponds to chapter 9.3 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$N_d = FX$ Design value of the axial force..

$M_{y,d} = My \text{ or } Mz$ Design value of the bending moment along the relevant axis of bending.

$M_{z,d} = Mz \text{ or } My$ Design value of the bending moment about the secondary axis of bending.

2. Class definition and effective section properties calculation.

The section class is determined by the general processing of the sections with the previously selected forces and moments if the selected option is partial, or with all the forces and moments if the selected option is full. These calculations are accomplished with the gross section properties.

3. Criteria calculation.

For members subjected to bi-axial bending and in absence of shear force, the following conditions at each section are checked:

Class 1 and 2 sections:

$$\left(\frac{M_{y,d}}{M_{Ny,Rd}}\right)^\alpha + \left(\frac{M_{z,d}}{M_{Nz,Rd}}\right)^\beta \leq 1$$

This condition is equivalent to:

$$\text{Crt_My} = (\text{Crt_My})^\alpha + (\text{Crt_Mz})^\beta \leq 1$$

$$\text{Crt_My} = \left(\frac{M_{y,d}}{M_{Ny,Rd}}\right)$$

$$\text{Crt_Mz} = \left(\frac{M_{z,d}}{M_{Nz,Rd}}\right)$$

Where $M_{Ny,Rd}$ and $M_{Nz,Rd}$ are the design moment resistance of the cross-section, reduced by the presence of the axial force:

$$M_{Ny,Rd} = My_{pl,Rd} \left[1 - \left(\frac{N_d}{N_{pl,Rd}} \right)^2 \right]$$

$$M_{Nz,Rd} = Mz_{pl,Rd} \left[1 - \left(\frac{N_d}{N_{pl,Rd}} \right)^2 \right]$$

Where α and β are constants, which may take the following values:

For I and H sections:

$$\alpha = 2 \quad \text{and} \quad \beta = 5n \quad \beta \geq 1$$

For circular tubes:

$$\alpha = 2 \quad \text{and} \quad \beta = 2$$

For rectangular hollow sections:

$$\alpha = \beta = \frac{1.66}{1-1.13n^2} \quad \text{but} \quad \alpha = \beta \leq 6$$

For solid rectangles and plates (the rest of sections):

$$\alpha = \beta = 1.73 + 1.8n^3$$

$$n = \left(\frac{N_d}{N_{pl.Rd}} \right)$$

In absence of $M_{z,d}$, the previous check can be reduced to:

$$\left(\frac{M_{y,d}}{M_{Ny.Rd}} \right) \leq 1$$

Condition equivalent to:

$$Crt_TOT = Crt_My = \left(\frac{M_{y,d}}{M_{Ny.Rd}} \right)$$

Class 3 sections (without holes for fasteners):

$$\left(\frac{N_d}{Af_{yd}} \right) + \left(\frac{M_{y,d}}{W_{el,y}f_{yd}} \right) + \left(\frac{M_{z,d}}{W_{el,z}f_{yd}} \right) \leq 1$$

Condition equivalent to:

$$Crt_TOT = Crt_N + Crt_My + Crt_Mz \leq 1$$

$$Crt_N = \left(\frac{N_d}{Af_{yd}} \right)$$

$$Crt_My = \left(\frac{M_{y,d}}{W_{el,y}f_{yd}} \right)$$

$$Crt_Mz = \left(\frac{M_{z,d}}{W_{el,z}f_{yd}} \right) f_{yd} = f_y / \gamma_{M0}$$

Where $W_{el,y}$ is the elastic resistant modulus about the y axis and $W_{el,z}$ is the elastic resistant modulus about the z axis.

In absence of $M_{z,d}$, the above criterion becomes:

$$\left(\frac{N_d}{Af_{yd}} \right) + \left(\frac{M_{y,d}}{W_{el,y}f_{yd}} \right) \leq 1$$

Which is equivalent to:

$$Crt_TOT = Crt_N + Crt_My \leq 1$$

$$Crt_N = \left(\frac{N_d}{Af_{yd}} \right)$$

$$Crt_My = \left(\frac{M_{y,d}}{W_{el,y}f_{yd}} \right)$$

Class 4 sections:

$$\left(\frac{N_d}{A_{\text{eff}} f_{yd}} \right) + \left(\frac{M_{y,d} + N_d e_{Ny}}{W_{\text{eff},y} f_{yd}} \right) + \left(\frac{M_{z,d} + N_d e_{Nz}}{W_{\text{eff},z} f_{yd}} \right) \leq 1$$

Condition equivalent to:

$$\text{Crt_TOT} = \text{Crt_N} + \text{Crt_My} + \text{Crt_Mz} \leq 1$$

$$\text{Crt_N} = \left(\frac{N_d}{A_{\text{eff}} f_{yd}} \right)$$

$$\text{Crt_My} = \left(\frac{M_{y,d} + N_d e_{Ny}}{W_{\text{eff},y} f_{yd}} \right)$$

$$\text{Crt_Mz} = \left(\frac{M_{z,d} + N_d e_{Nz}}{W_{\text{eff},z} f_{yd}} \right)$$

Where:

A_{eff}	effective area of the cross-section
$W_{\text{eff},y}$	effective section modulus of the cross-section when subjected to a moment about the y axis
$W_{\text{eff},z}$	effective section modulus of the cross-section when subjected to a moment about the z axis
e_{Ny}	shift of the center of gravity along the y axis
e_{Nz}	shift of the center of gravity along the z axis

Without $M_{z,d}$, the above criterion becomes:

$$\left(\frac{N_d}{A_{\text{eff}} f_{yd}} \right) + \left(\frac{M_{y,d} + N_d e_{Ny}}{W_{\text{eff},y} f_{yd}} \right) + \left(\frac{N_d e_{Nz}}{W_{\text{eff},z} f_{yd}} \right) \leq 1$$

which is equivalent to:

$$\text{Crt_TOT} = \text{Crt_N} + \text{Crt_My} + \text{Crt_Mz} \leq 1$$

$$\text{Crt_N} = \left(\frac{N_d}{A_{\text{eff}} f_{yd}} \right)$$

$$\text{Crt_My} = \left(\frac{M_{y,d} + N_d e_{Ny}}{W_{\text{eff},y} f_{yd}} \right)$$

$$\text{Crt_Mz} = \left(\frac{N_d e_{Nz}}{W_{\text{eff},z} f_{yd}} \right)$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-6 Checking of Members under Bending Moment + Axial Force and Bi-axial Bending + Axial Force

Result	Concepts	Description
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Result	Concepts	Description
NED	N_{Ed}	Design value of the axial force.
MYED	$M_{y.Ed}$	Design value of the bending moment about Y axis.
MZED	$M_{z.Ed}$	Design value of the bending moment about Z axis.
NCRD	$A \cdot f_{yd},$ $A_{eff} \cdot f_{yd}$	Design compression resistance of the cross-section
MNYRD	$M_{Ny.Rd}, W_{el.y} \cdot f_{yd},$ $W_{eff.y} \cdot f_{yd}$	Reduced design moment resistance of the cross-section about Y axis
MNZRD	$M_{Nz.Rd}, W_{el.z} \cdot f_{yd},$ $W_{eff.z} \cdot f_{yd}$	Reduced design moment resistance of the cross-section about Z axis
CRT_N	N_d/N_{cRd}	Axial criterion
CRT_MY	M_{yd}/M_{NyRd}	Bending criterion along Y
CRT_MZ	M_{zd}/M_{NzRd}	Bending criterion along Z
ALPHA	α	Alpha constant
BETA	β	Beta constant
CRT_TOT	$Crt_{tot} \leq 1$	IS 800:2007 global criterion
CLASS		Section Class
AREA	A, A_{eff}	Area of the section utilized (Gross or Effective)
WY	$W_{el.y}, W_{pl.y}, W_{eff.y}$	Used section Y modulus (Elastic, Plastic or Effective)
WZ	$W_{el.z}, W_{pl.z}, W_{eff.z}$	Used section Z modulus (Elastic, Plastic or Effective)
SIGXED	$\sigma_{X.Ed}$	Maximum longitudinal stress
ENY	e_{Ny}	Shift of the Z axis in Y direction
ENZ	e_{Nz}	Shift of the Y axis in Z direction
USE_MY	$M_{y.d} + N_d \cdot e_{Ny}$	Modified design value of the bending moment about Y axis
USE_MZ	$M_{z.d} + N_d \cdot e_{Nz}$	Modified design value of the bending moment about Z axis
PARM_N	n	Parameter n

10-N.7.8 Checking for Buckling of Compression Members

Corresponds to chapter 8 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered in this checking type are:

$$N_d = FX \quad \text{Design value of the axial force (positive if compressive, otherwise element is not processed). Represented as } P_d.$$

2. Class definition and effective section properties calculation.

The section class is determined by the sections general processing with the previously selected forces and moments if the selected option is partial, or with all the forces and moments if the selected option is full. The entire calculation is accomplished with the gross section properties.

3. Criteria calculation.

When checking the buckling of compression members, the criterion is given by:

$$N_d \leq N_{b,Rd} \quad \rightarrow \quad Crt_TOT = Crt_CB = \frac{N_d}{N_{b,Rd}} \leq 1$$

where:

$$N_{b,Rd} \quad \text{Design buckling resistance. } N_{b,Rd} = \chi \beta A f_y / \gamma_{M1}$$

$$\beta = 1 \text{ for class 1, 2 or 3 sections.}$$

$$\beta = A_{eff} / A \text{ for class 4 sections.}$$

$$\chi \quad \text{Reduction factor for the relevant buckling mode, the program does not consider the torsional or the lateral-torsional buckling.}$$

The χ calculation in members of constant cross-section may be determined from:

$$\chi = \frac{1}{\Phi + (\Phi^2 - \bar{\lambda}^2)^{1/2}} \leq 1$$

$$\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$$

where α is an imperfection factor that depends on the buckling curve. This curve depends on the cross-section type, producing the following values for α :

Table 10-N.7-7 Imperfection factor α for IS-800-2007

Section type	Limits	Buckling axis	Buckling curve	α
Rolled I	$h/b > 1.2$ and $t_f \leq 40\text{mm}$	$y - y$	a	0.21
Rolled I	$h/b > 1.2$ and $t_f \leq 40\text{mm}$	$z - z$	b	0.34
Rolled I	$h/b > 1.2$ and $40\text{mm} < t_f \leq 100\text{mm}$	$y - y$	b	0.34
Rolled I	$h/b > 1.2$ and $40\text{mm} < t_f \leq 100\text{mm}$	$z - z$	c	0.49
Rolled I	$h/b \leq 1.2$ and $t_f \leq 100\text{mm}$	$y - y$	b	0.34
Rolled I	$h/b \leq 1.2$ and $t_f \leq 100\text{mm}$	$z - z$	c	0.49

Rolled I	tf>100mm	y – y	d	0.76
Rolled I	tf>100mm	z – z	d	0.76
Welded I	tf ≤ 40mm	y – y	b	0.34
Welded I	tf ≤ 40mm	z – z	c	0.49
Welded I	tf >40mm	y – y	c	0.49
Welded I	tf >40mm	z – z	d	0.76
Rolled box and pipe	-	Any	a	0.21
Welded box and pipe (Using fyb)	-	Any	b	0.34
Welded box in other case	-	Any	b	0.34
Welded box	b/tf <30	y – y	c	0.49
Welded box	h/tw <30	z – z	c	0.49
U, L and T	-	Any	c	0.49

$$\bar{\lambda} = [\beta_A A f_y / N_{cr}]^{1/2}$$

Where N_{cr} is the elastic critical force for the relevant buckling mode. (See section for Critical Forces and Moments Calculation).

The elastic critical axial forces are calculated in the planes XY ($N_{cr_{xy}}$) and XZ ($N_{cr_{xz}}$) and the corresponding values of χ_{xy} and χ_{xz} , taking the smaller one as the final value for χ .

$$\chi = \min(\chi_{xy}, \chi_{xz})$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-8 Checking for Buckling of Compression Members

Result	Concepts	Description
NED	N_{Ed}	Design value of the compressive force.
NBRD	$N_{b.Rd}$	Design buckling resistance of a compressed member.
CRT_CB	$N_d / N_{b.Rd}$	Compression buckling criterion.
CRT_TOT	$N_d / N_{b.Rd}$	IS 800:2007 global criterion.
CHI	$\text{Min}\{\chi_y, \chi_z\}$	Reduction factor for the relevant buckling mode.
BETA_A	β_A	Ratio of the used area to gross area.
AREA	A	Area of the gross section.

Result	Concepts	Description
CHI_Y	χ_y	Reduction factor for the relevant My buckling mode.
CHI_Z	χ_z	Reduction factor for the relevant Mz buckling mode.
CLASS		Section Class.
PHI_Y	Φ_y	Parameter Phi for bending My.
PHI_Z	Φ_z	Parameter Phi for bending Mz.
LAM_Y	λ_y	Non-dimensional reduced slenderness for bending My.
LAM_Z	λ_z	Non-dimensional reduced slenderness for bending Mz.
NCR_Y	N_{cr}	Elastic critical force for the relevant My buckling mode.
NCR_Z	N_{cr}	Elastic critical force for the relevant Mz buckling mode.
ALP_Y	α_y	Imperfection factor for bending My.
ALP_Z	α_z	Imperfection factor for bending Mz.

10-N.7.9 Checking Lateral-Torsional Buckling of Members Subjected to Combined Bending and Axial Tension

Corresponds to chapter 9.3 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered for this checking type are:

$$N_{sd} = FX \quad \text{Design value of the axial force (positive if tensile, otherwise element not processed if compressive).}$$

$$M_{sd} = My \text{ or } Mz \quad \text{Design value of the bending moment about the relevant bending axis.}$$

2. Class definition and effective section properties calculation.

The section class is determined by the general processing of sections with the previously selected forces and moments if the selected option is partial, or with all the forces and moments if the selected option is full. The entire calculation is accomplished with the gross section properties.

3. Criteria calculation.

With checking lateral-torsional buckling of members subjected to combined bending and axial tension, the value of the axial force is multiplied by a reduction factor

Ψ_{vec} in order to consider the axial force and bending moment as a vector

magnitude.

The value of Ψ_{vec} depends on the country where the code will be applied. That factor is introduced as a property at member level, and typically its value is equal to: $\Psi_{vec} = 0.8$

The stress in the extreme compression fiber is calculated as follows:

$$\sigma_{com.ed} = \frac{M_{Sd}}{W_{com}} - \frac{\Psi_{vec} N_{t.Sd}}{A}$$

Where W_{com} is the elastic section modulus for the extreme compression fiber and $N_{t.Sd}$ is the design value of the axial tension.

The verification equation is derived to:

$$M_{eff.Sd} < M_{b.Rd} \rightarrow Crt_TOT = Crt_LT = \frac{M_{eff.Sd}}{M_{b.Rd}} \leq 1$$

Where:

$$M_{eff.Sd} = W_{com} \sigma_{com.ed}$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-9 Art. 5.5.3 Checking Lateral-Torsional Buckling of Members Subjected to Combined Bending and Axial Tension

Results	Concepts	Description
NTSD	$N_{t.Sd}$	Design value of the axial tension.
MSD	M_{Sd}	Design value of the bending moment.
MEFFSD	$M_{eff.Sd}$	Effective design internal moment.
MBRD	$M_{b.Rd}$	Buckling resistance moment of a laterally unrestrained beam.
CRT_LT	$M_{eff.Sd}/M_{b.Rd}$	Lateral-torsional buckling criterion.
CRT_TOT	$M_{eff.Sd}/M_{b.Rd}$	IS 800:2007 global criterion.
CLASS		Section Class.
WCOM	W_{com}	Elastic section modulus for the extreme compression fiber.
SCOMED	$\sigma_{Com.Ed}$	Net calculated stress in the extreme compression fiber.
CHI_LT	χ_{LT}	Reduction factor for lateral-torsional buckling.
BETA_W	β_w	Ratio of the used modulus to plastic modulus.
WPL	W_{ply}	Plastic modulus.
PHI_LT	Φ_{LT}	Parameter Phi for lateral-torsional buckling.
LAM_LT	λ_{LT}	Esbeltez adimensional reducida.
MCR	M_{cr}	Elastic critical moment for lateral-torsional buckling.

ALP_LT	α_{LT}	Non-dimensional reduced slenderness.
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10-N.7.10 Checking for Lateral-Torsional Buckling of Members Subjected to Bending and Axial Compression

Corresponds to chapter 9.3 in IS-800-2007.

1. Forces and moments selection.

The forces and moments considered in this checking type are:

$N_d = FX$ Design value of the axial compression (positive if compressive, otherwise element not processed if tensile).

$M_{yd} = My \text{ or } Mz$ Design value of the bending moment about the relevant axis of bending.

$M_{zd} = Mz \text{ or } My$ Design value of the bending moment about the secondary axis of bending.

2. Class definition and effective section properties calculation.

The section class is determined by the general processing of sections with the previously selected forces and moments if the selected option is partial, or with all the forces and moments if the selected option is full. The entire calculation is accomplished with the gross section properties.

3. Criteria calculation.

When checking the lateral-torsional buckling of members subjected to combined bending and axial compression, the criterion to satisfy is as follows:

$$\left| \frac{N_d}{N_{b.Rd}} \right| + \left| \frac{M_{y.d}}{M_{yb.Rd}} \right| + \left| \frac{M_{z.d}}{M_{zb.Rd}} \right| \leq 1 \rightarrow \text{Crt_TOT} = \text{Crt_N} + \text{Crt_My} + \text{Crt_Mz} \leq 1$$

where:

Crt_TOT IS 800:2007 global criterion.

$\text{Crt_N} = \left| \frac{N_d}{N_{b.Rd}} \right|$ Axial criterion.

$\text{Crt_My} = \left| \frac{M_{y.d}}{M_{yb.Rd}} \right|$ Bending criterion (principal axis).

$\text{Crt_Mz} = \left| \frac{M_{z.d}}{M_{zb.Rd}} \right|$ Bending criterion (secondary axis).

$N_{b.Rd}$ Design buckling resistance for compression.

$M_{yb.Rd}$ Design buckling resistance moment (principal axis)

$M_{zb.Rd}$ Design buckling resistance moment (secondary axis).

The member resistances depend on the cross-section class and on the possibility that the lateral-torsional buckling is a potential failure mode for the structure.

Members with *class 1* and *2* cross-sections shall satisfy:

$$\frac{N_d}{\chi_{\min} A f_y / \gamma_{M1}} + \frac{k_y M_{y,d}}{W_{pl,y} f_y / \gamma_{M1}} + \frac{k_z M_{z,d}}{W_{pl,z} f_y / \gamma_{M1}} \leq 1$$

where:

$$k_y = 1 - \frac{\mu_y \cdot N_d}{\chi_y \cdot A \cdot f_y} \leq 1.5$$

$$\mu_y = \bar{\lambda}_y (2\beta_{My} - 4) + \left[\frac{W_{pl,y} - W_{el,y}}{W_{el,y}} \right] \quad \mu_y \leq 0.90$$

$$k_z = 1 - \frac{\mu_z N_d}{\chi_z A f_y} k_z \leq 1.5$$

$$\mu_z = \bar{\lambda}_z (2\beta_{Mz} - 4) + \left[\frac{W_{pl,z} - W_{el,z}}{W_{el,z}} \right] \quad \mu_z \leq 0.90$$

$$\chi_{\min} = \min(\chi_y; \chi_z)$$

Where:

χ_y and χ_z are the reduction factors defined at the section corresponding to Checking for Buckling of Compression Members.

β_{My} and β_{Mz} are equivalent uniform moment factors for flexural bending. These factors are entered as properties at member level (**~MEMBPRO** command). (See section Data at Member Level, factors BetaMy and BetaMz).

Members with Class 1 and 2 cross-sections for which lateral-torsional buckling is a potential failure mode shall satisfy:

$$\frac{N_d}{\chi_z A f_y / \gamma_{M1}} + \frac{k_{LT} M_{y,d}}{\chi_{LT} W_{pl,y} f_y / \gamma_{M1}} + \frac{k_z M_{z,d}}{W_{pl,z} f_y / \gamma_{M1}} \leq 1$$

where:

$$k_{LT} = 1 - \frac{\mu_{LT} \cdot N_d}{\chi_z \cdot A \cdot f_y} \leq 1$$

$$\mu_{LT} = 0.15 \bar{\lambda} C_{M,LT} - 0.15 \quad \mu_{LT} \leq 0.90$$

where $C_{M,LT}$ is an equivalent uniform moment factor for lateral-torsional buckling. This factor, as the precedent factors C_{My} and C_{Mz} , is introduced as a member property. (See section data at Member Level, factor C_{Mlt}).

Members with *Class 3* cross-sections shall satisfy:

$$\frac{N_d}{\chi_{\min} A f_y / \gamma_{M1}} + \frac{k_y M_{y,d}}{W_{el,y} f_y / \gamma_{M1}} + \frac{k_z M_{z,d}}{W_{el,z} F_y / \gamma_{M1}} \leq 1$$

where k_y , k_z and χ_{\min} are as for Class 1 and 2 cross-sections.

$$\begin{aligned}\mu_y &= \bar{\lambda}_y(2\beta_{My} - 4) & \mu_y &\leq 0.90 \\ \mu_z &= \bar{\lambda}_z(2\beta_{Mz} - 4) & \mu_z &\leq 0.90\end{aligned}$$

Members with Class 3 cross-sections for which lateral-torsional buckling is a potential failure mode shall satisfy:

$$\frac{N_d}{\chi_z A f_y / \gamma_{M1}} + \frac{k_y M_{y,d}}{\chi_{LT} W_{el,y} f_y / \gamma_{M1}} + \frac{k_z M_{z,d}}{W_{el,z} F_y / \gamma_{M1}} \leq 1$$

Members with Class 4 cross-sections shall satisfy:

$$\frac{N_d}{\chi_{min} A f_y / \gamma_{M1}} + \frac{k_y (M_{y,d} + N_d e_{Ny})}{W_{eff,y} f_y / \gamma_{M1}} + \frac{k_z (M_{z,d} + N_d e_{Nz})}{W_{el,z} F_y / \gamma_{M1}} \leq 1$$

where:

k_y, k_z and χ_{min}	are the same as for class 1 and 2 cross-sections, but use the effective area A_{eff} , instead of the gross area A .
μ_y and μ_z	are the same as for class 3 cross-sections, but add the moment $N_d \cdot e_N$ that appears by the shift of the center of gravity in the effective cross-section, when determining C_{My} and C_{Mz} .
$A_{eff}, W_{eff,y}, W_{eff,z}, e_{N,y}, e_{Nz}$	are defined in the section corresponding to Checking of members under bending and axial force and bi-axial bending.

Members with Class 4 cross-sections for which lateral-torsional buckling is a potential failure mode shall satisfy:

$$\frac{N_d}{\chi_z A f_y / \gamma_{M1}} + \frac{k_{LT} (M_{y,d} + N_d e_{Ny})}{\chi_{LT} W_{el,y} f_y / \gamma_{M1}} + \frac{k_z (M_{z,d} + N_d e_{Nz})}{W_{el,z} F_y / \gamma_{M1}} \leq 1$$

where:

k_{LT}	is similar to class 1 and 2 cross-sections, but uses the effective area A_{eff} , instead of the gross area A .
μ_{Lt}	is similar to class 2 cross-sections, but adds the moment $N_d \cdot e_N$ that appears by the shift of the center of gravity in the effective cross-section, when determining β_{MLT} .

Checking Parameters:

Class	A	W_y	W_z	α_y	α_z	$e_{N,y}$	$e_{N,z}e_{N,z}$
1	A	$W_{pl,y}$	$W_{pl,z}$	0.6	0.6	0	0
2	A	$W_{pl,y}$	$W_{pl,z}$	0.6	0.6	0	0
3	A	$W_{el,y}$	$W_{el,z}$	0.8	1	0	0
4	A_{eff}	$W_{el,y}$	$W_{eff,z}$	0.8	1	Depending on members and stresses	Depending on members and stresses

Interaction Factors:

Class	Section type	k_y	k_z	k_{yLT}
1 y 2	I, H	$1 + (\bar{\lambda}_y - 0.2) \frac{N_{Ed}}{\chi_y N_{C,Rd}}$	$1 + (\bar{\lambda}_z - 0.6) \frac{N_{Ed}}{\chi_z N_{C,Rd}}$	$1 - \frac{0.1 \cdot \bar{\lambda}_z}{(C_{mLT} - 0.25)} \cdot \frac{N_{Ed}}{\chi_z N_{C,Rd}} \cdot 0.6 + \bar{\lambda}_z$
	RHS		$1 + (\bar{\lambda}_y - 0.2) \frac{N_{Ed}}{\chi_z N_{C,Rd}}$	
3 y 4	All sections	$1 + 0.6 \bar{\lambda}_y \frac{N_{Ed}}{\chi_y N_{C,Rd}}$	$1 + 0.6 \bar{\lambda}_z \frac{N_{Ed}}{\chi_z N_{C,Rd}}$	$1 - \frac{0.05 \cdot \bar{\lambda}_z}{(C_{mLT} - 0.25)} \cdot \frac{N_{Ed}}{\chi_z N_{C,Rd}}$

where:

λ_y y λ_z Limited slenderness values for y-y and z-z axes, less than 1.

$$N_{C,Rd} = A \cdot \frac{f_y}{\gamma_{M1}}$$

4. Output results are written in the CivilFEM results file (.RCV) as an alternative. Checking results: criteria and variables are described in the following table.

Table 10-N.7-10 Checking for Lateral-Torsional Buckling of Members Subjected to Bending and Axial Compression

Result	Concepts	Description
NED	N_{Ed}	Design value of the axial compression force.
MYED	$M_{y,Ed}$	Design value of the bending moment about Y

Result	Concepts	Description
		axis.
MZED	$M_{z,Ed}$	Design value of the bending moment about Z axis.
NBRD1	$\chi_y \cdot A \cdot f_y / \gamma_{M1}$	Design compression resistance of the cross-section.
MYRD1	$\chi_{LT} \cdot W_y \cdot f_y / \gamma_{M1}$	Reduced design moment resistance of the cross-section about Y axis.
MZRD1	$W_z \cdot f_y / \gamma_{M1}$	Reduced design moment resistance of the cross-section about Z axis.
NBRD2	$\chi_z \cdot A f_y / \gamma_{M1}$	Design compression resistance of the cross-section.
MYRD2	$\chi_{LT} \cdot W_y \cdot f_y / \gamma_{M1}$	Reduced design moment resistance of the cross-section about Y axis.
MZRD2	$W_z \cdot f_y / \gamma_{M1}$	Reduced design moment resistance of the cross-section about Z axis.
K_Y	K_y	Parameter K_y .
K_Z	K_z	Parameter K_z .
K_LT	K_{LT}	Parameter K_{LT} .
CRT_N1	N_{Ed} / N_{cRd1}	Axial criterion.
CRT_MY1	$K_y C_{my} (M_{y,Ed} + N_{Ed} \cdot e_{Ny}) / M_{yb,Rd1}$	Bending Y criterion.
CRT_MZ1	$\alpha_z \cdot K_z \cdot C_{mz} (M_{z,Ed} + N_{Ed} e_{Nz}) / M_{zb,Rd1}$	Bending Z criterion.
CRT_1	CRT_N1+CRT_MY1 +CRT_MZ1	Criterion 1
CRT_N2	N_{Ed} / N_{cRd2}	Axial criterion.
CRT_MY2	$K C_{my} (M_{y,Ed} + N_{Ed} \cdot e_{Ny}) / M_{yRd2}$	Bending Y criterion. $K=K_{yLT}$ if torsion exists and if not present $K=\alpha_y K_y$
CRT_MZ2	$K_z \cdot C_{mz} (M_{z,Ed} + N_{Ed} \cdot e_{Nz}) / M_{zRd2}$	Bending Z criterion.
CRT_2	CRT_N2+CRT_MY2 +CRT_MZ2	Criterion 2
CRT_TOT	$Crt_{tot} \leq 1$	IS 800:2007 global criterion.

Result	Concepts	Description
CLASS		Section Class.
CHIMIN	$Min\{\chi_y, \chi_z\}$	Reduction factor for the relevant buckling mode.
CHI_Y	χ_y	Reduction factor for the relevant My buckling mode.
CHI_Z	χ_z	Reduction factor for the relevant Mz buckling mode.
CHI_LT	χ_{LT}	Reduction factor for lateral-torsional buckling.
AREA	A, A _{eff}	Used area of the section (Gross or Effective).
WY	W _{el.y} , W _{pl.y} , W _{eff.y}	Used section Y modulus (Elastic, Plastic or Effective).
WZ	W _{el.z} , W _{pl.z} , W _{eff.z}	Used section Z modulus (Elastic, Plastic or Effective).
ENY	e _{Ny}	Shift of the Z axis in Y direction.
ENZ	e _{Nz}	Shift of the Y axis in Z direction.
NCR_Y	N _{cr}	Elastic critical force for the relevant My buckling mode.
NCR_Z	N _{cr}	Elastic critical force for the relevant Mz buckling mode.
MCR	M _{cr}	Elastic critical moment for lateral-torsional buckling.
LAM_Y	λ_y	Non-dimensional reduced slenderness for bending My.
LAM_Z	λ_z	Non-dimensional reduced slenderness for bending Mz.
LAM_LT	λ_{LT}	Non-dimensional reduced slenderness for lateral-torsional buckling.

10-N.7.11 Critical Forces and Moments Calculation

The critical forces and moments $N_{cr_{xy}}$, $N_{cr_{xz}}$ and M_{cr} , are needed for the different types of buckling checks. They are calculated based on the following formulation:

$$N_{cr_{xy}} = \frac{AE\pi^2}{\lambda_{xy}^2} = AE \left(\frac{\pi i_{xy}}{L_{xy}} \right)^2$$

$$N_{cr_{xz}} = \frac{AE\pi^2}{\lambda_{xz}^2} = AE \left(\frac{\pi i_{xz}}{L_{xz}} \right)^2$$

where:

$N_{cr_{xy}}$	Elastic critical axial force in plane XY.
$N_{cr_{xz}}$	Elastic critical axial force in plane XZ.
A	Gross area.
E	Elasticity modulus.
λ_{xy}	Member slenderness in plane XY.
λ_{xz}	Member slenderness in plane XZ.
i_{xy}	Radius of gyration of the member in plane XY.
i_{xz}	Radius of gyration of the member in plane XZ.
L_{xy}	Buckling length of member in plane XY.
L_{xz}	Buckling length of member in plane XZ.

The buckling length in both planes is the length between the ends restrained against lateral movement and it is obtained from the member properties, according to the following expressions:

$$L_{xy} = L \cdot C_{fbuckxy}$$

$$L_{xz} = L \cdot C_{fbuckxz}$$

where:

$C_{fbuckxy}$	Buckling factor in plane XY.
$C_{fbuckxz}$	Buckling factor in plane XZ.

For the calculation of the elastic critical moment for lateral-torsional buckling, M_{cr} , the following equation shall be used. This equation is *only valid for uniform symmetrical cross-sections about the minor axis* (Annex E, IS 800:2007). IS 800:2007 does not provide a method for calculating this moment in nonsymmetrical cross-sections or sections with other symmetry plane (angles, channel section, etc.).

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(kL)^2} \left\{ \left[\left(\frac{k}{k_w} \right)^2 \frac{I_w}{I_z} + \frac{(kL)^2 G I_t}{\pi^2 E I_z} + [C_2 Z_g - C_3 Z_j]^2 \right]^{1/2} - [C_2 Z_g - C_3 Z_j] \right\}$$

$$Z_j = Z_s - \frac{0.5}{I_y} \int_A (y^2 + z^2) z \, dA$$

where:

M_{cr}	Elastic critical moment for lateral-torsional buckling.
C_1, C_2, C_3	Factors depending on the loading and end restraint conditions.
k, k_w	Effective length factors.
E	Elasticity modulus.
I_y	Moment of inertia about the principal axis.
I_z	Moment of inertia about the minor axis.
L	Length of the member between end restraints.
G	Shear modulus.
Z_g	$Z_a - Z_s$
Z_a	Coordinate of the point of load application. ANSYS always considers that the load is applied at the center of gravity, therefore: $Z_a = 0$.
Z_s	Coordinate of the shear center.
A	Cross-section area.

Factors C and k are read from the properties at member level (~MEBMPRO command).

The integration of the previous equation is calculated as a summation extending to each plate. This calculation is accomplished for each plate according to its ends coordinates:

y_1, Z_1 and y_2, Z_2 and its thicknesses.

$$\int_A (y^2 + z^2) z \, dA = \sum_{i=1}^{nplates} S_i * \int_{L_i} (y^2 + z^2) z \, dl$$

where:

S_i = thickness of plate i

$$dA = S_i * dl$$

$$y = y_1 + l * \cos\alpha$$

$$z = z_1 + l * \sin\alpha$$

$$\alpha = \arctang \frac{z_2 - z_1}{y_2 - y_1}$$

$$L_i = \sqrt{(y_1 - y_2)^2 + (z_1 - z_2)^2} = \text{plate width}$$

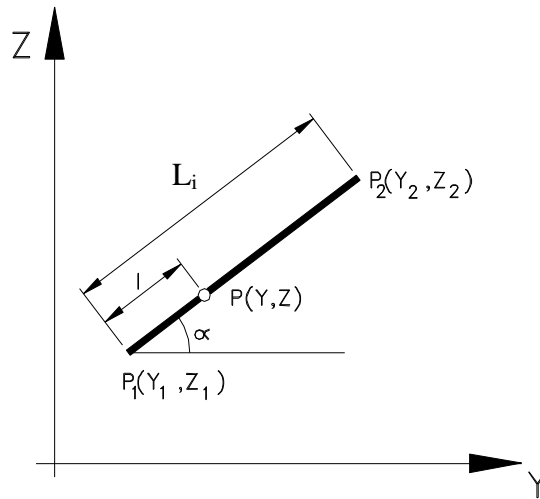


Figure 10-N.7-6