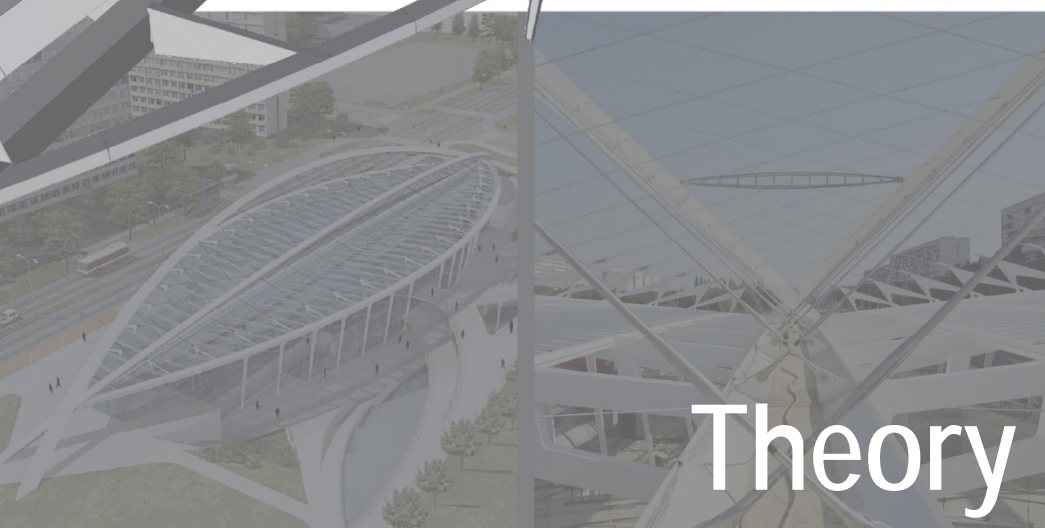
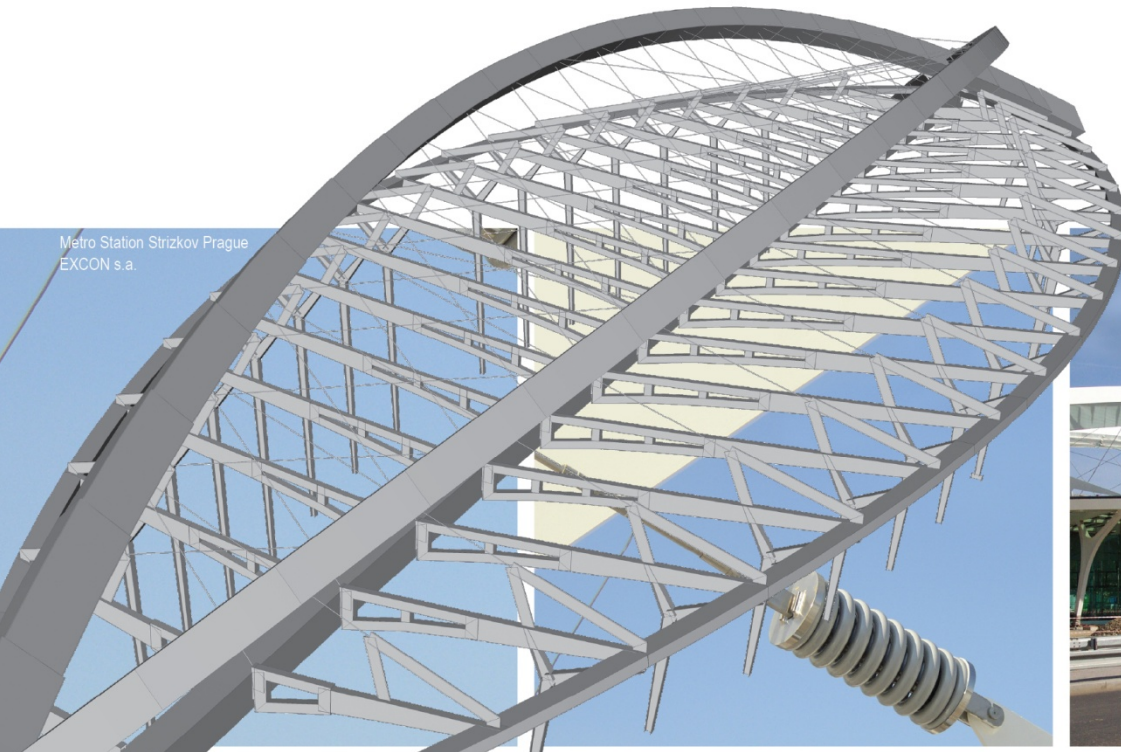


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# Theory

BS 5950-1: 2000 steel code check

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## Introduction

This document briefly explains the theoretical background for the design check of steel members in accordance with BS 5950-1:2000 in ESA PT. The following additional checks are also provided using the listed references to supplement BS 5950 namely: the effect of torsion<sup>4</sup>, members curved in elevation<sup>5</sup>, members curved in plan<sup>6</sup>, cellular members<sup>7</sup> and castellated members<sup>8</sup>.

# Steelwork code check to BS 5950-1:2000

## Introduction

Steel members are checked under ultimate and serviceability limit state load combinations according to BS 5950-1:2000. Under ultimate limit state (ULS) load combinations, each section is checked for the limit state of strength and each potential buckling segment is checked for the stability limit state. Under serviceability limit state (SLS) load combinations, each span is checked for deflection and (where applicable) twist.

### Properties of material

For standard steel grades, the design strength  $p_y$  is defined according to the thickness of the element (see Table 9 Cl.3.1.1.). The partial safety factor on design strength is included in the  $p_y$  value.

The standard steel grades are:

Grade S275: yield strength defined between 225 and 275 N/mm<sup>2</sup>

Grade S355: yield strength defined between 295 and 355 N/mm<sup>2</sup>

Grade S460: yield strength defined between 400 and 460 N/mm<sup>2</sup>

Steel grade	Thickness limits (mm)	$P_y$ (N/mm <sup>2</sup> )
Grade S275	$t \leq 16$	275
	$t \leq 40$	265
	$t \leq 63$	255
	$t \leq 80$	245
	$t \leq 100$	235
	$t \leq 150$	225
Grade S355	$t \leq 16$	355
	$t \leq 40$	345
	$t \leq 63$	335
	$t \leq 80$	325
	$t \leq 100$	315
	$t \leq 150$	295
Grade S460	$t \leq 16$	460
	$t \leq 40$	440
	$t \leq 63$	430
	$t \leq 80$	410
	$t \leq 100$	400

Note that the reduced yield/design stresses given in the above table are only applied when the steel material is chosen from the designated grades S275, S355 or S460.

For all other grades,  $P_y$  = lesser of yield strength and (ultimate tensile strength / 1.2). (see Cl.3.1.1)

### Design strength: $p_y$

The design strength depends on the steel ultimate tensile strength, yield stress and section thickness per BS5950-1:2000 clause 3.1.1 and Table 9.

### Stress index: epsilon $\Sigma$

This is the local buckling parameter defined in BS5950-1:2000 Table 11.

## Properties of cross section

This code check requires the following cross section properties:

Description	BS5950-1:2000 symbols	ESAPT symbols
Distance from the bottom to the centroidal axis x	Cx	cYLCS
Distance from the Left to the centroidal axis y	Cy	cZLCS
Area of the section	Ag	A
Angle between coordinate(xx) axis to principle axis(uu)	Alpha	alpha
Second moment of area about uu axis	Iu	Iy
Second moment of area about vv axis	Iv	Iz
Second moment of area about xx axis	Ix	IY
Second moment of area about yy axis	Iy	Iz
Plastic modulus about xx axis	Sx	Wply
Plastic modulus about yy axis	Sy	Wplz
Plastic modulus of the effective section excluding the shear area about xx axis	Sfx	-
Plastic modulus of the effective section excluding the shear area about yy axis	Sfy	-
Elastic modulus of the effective section excluding the shear area about xx axis	Zfy	-
Elastic modulus about xx axis at top fibre	Zx at top fibre	Wely at top fibre
Elastic modulus about xx axis at lowest fibre	Zx at lowest fibre	Wely at lowest fibre
Elastic modulus about yy axis at extreme left fibre	Zy at extreme left fibre	Welz at extreme left fibre
Elastic modulus about yy axis at extreme right fibre	Zy at extreme right fibre	Welz at extreme right fibre
Torsional constant	J	It
Warping constant	H	Iw
Torsional modulus constant	C	Wt
Static Moment for web	Qw	-
Static Moment for flange	Qf	-

## Strength checks

Strength (local capacity) check results are calculated and made available at each effects position.

### Tension check

Axial tension force

Applied axial force at the current position  
Axial tension force is assumed to be negative.

Effective tension area

The net area of a section is taken as its gross section neglecting the deduction due to bolt holes given in 3.4.4

Tension capacity

Tension capacity = design strength x effective tension area

Utilisation Ratio

Utilisation Ratio = Axial tension force / Tension capacity

Axial tension capacity results (clause 4.6)

These results will not be displayed, if the axial force is zero or compression

## Cross-section classification

This result will not be displayed, if only tensile force is present at the current position.  
Section classification is determined in accordance with BS 5950-1:2000 clause 3.5 and tables 11 and 12

### Axis definition:

- local x-axis in this code check refers to the local y axis in SCIA ESA PT
- local y-axis in this code check refers to the local z axis in SCIA ESA PT

### Cross section classification for bending in normal direction

#### Flange slenderness: $b/T$

The flange buckling width or outstand defined in Figure 5 divided by the flange thickness.

#### Flange classification

The BS5950-1:2000 classification of the flange elements of the section for local buckling and rotation capacity described in 3.5.2 and Table 11 and 12.

#### Web slenderness: $d/t$

Web buckling depth as defined in Figure 5 divided by the web thickness.

#### Web classification

The BS5950-1:2000 classification of the web elements of the section for local buckling and rotation capacity described in 3.5.2 and Table 11 and 12.

#### Section classification

The complete cross section is classified according to the highest (least favourable) of its web and flange classifications.

#### 2.2.2.2 Cross section classification for bending in lateral direction

The calculation of classification in y is similar to that of the x axis, except that the appropriate values are used. Note that for rectangular hollow sections some of the web and flange parameters interchange for major and minor axis bending, whilst for other sections the values are common (refer note at bottom of Figure 5 in BS5950-1:2000)

#### 2.2.2.3 Web axial class

Web axial class is the classification under axial compression. Web axial class will be slender if either the flange class or web class is slender under axial compression.

If the cross section class is non-slender and web axial class is slender then design strength for axial compression is computed in accordance with reference<sup>2</sup>

#### 2.2.2.4 Effective section properties

##### Effective plastic modulus

A class 3 semi-compact section subject to bending is designed using the section modulus  $S_{eff}$  for I sections with equal flanges (clause 3.5.6.2), rectangular hollow sections (clause 3.5.6.3) and circular

hollow sections (clause 3.5.6.4). For all other cross sections the section modulus Z is used as recommended in clause 3.5.6.1

### **Effective area**

For doubly symmetric slender cross sections under pure compression, the effective area is calculated using clause 3.6.2.2. Note that fillet area is neglected in this calculation. For equal-leg angle sections and circular hollow sections,  $A_{eff}$  is calculated respectively in accordance with clause 3.6.4 and clause 3.6.6. For all other cross sections, the alternative method is used in accordance with clause 3.6.5 and the effective area is taken as gross area.

### **Effective elastic modulus**

For equal-leg angle and circular hollow slender cross sections, the effective elastic modulus  $Z_{eff}$  is calculated respectively in accordance with clause 3.6.4 and clause 3.6.6. For all other cross sections,  $Z_{eff}$  is taken as Z according to alternative method in accordance with clause 3.6.5.

### **Reduced design strength $P_{yr}$ for axial compression**

For slender cross sections, the alternative method of clause 3.6.5 implies using the gross section area with reduced design strength  $P_{yr} = (\text{Element slenderness} / \text{Element buckling limit})^2 * P_y$ , where the buckling limit under axial compression is based on the web axial class.

### **Reduced design strength $P_{yr}$ for bending**

For slender cross sections, the alternative method of clause 3.6.5 implies using the elastic section modulus Z with reduced design strength  $P_{yr} = (\text{Element slenderness} / \text{Element buckling limit})^2 * P_y$ , where the buckling limit under compression with bending based on corresponding cross-section class in major/minor direction.

## **Shear check**

The shear check is done in accordance with clause 4.2.3.

Shear force

Applied shear force  $F_v$  at the current position

Shear area

The plastic shear area  $A_v$  is calculated in accordance with 4.2.3.

Shear capacity

Shear capacity is calculated as:  $P_v = 0.6 \times P_y \times A_v$

Shear utilisation ratio

The sign of the shear force is ignored.

If  $F_v/P_v > 1.0$ , capacity is inadequate.

If  $F_v/P_v > 0.60$ , the plastic moment of resistance is reduced in accordance with 4.2.5.3.

### **Shear-buckling check**

If the ratio  $d/t$  exceeds  $70e$  for a rolled section, or  $62e$  for a welded section, the web is checked for shear buckling in accordance with 4.4.5

### **Shear reduction factor**

The reduction factor  $Rho$  for high shear condition is calculated from the formula in H.3.2.

### **Equivalent slenderness of web**

The equivalent slenderness of the web  $\lambda_w$  is calculated from the formula in H.1.

### **Buckling strength**

The buckling strength  $q_w$  is calculated from the formula in H.1.

### **Shear buckling capacity**

Shear buckling capacity is calculated in accordance with 4.4.5.2:-  $V_b = V_w = d \times t \times q_w$

### **Shear buckling utilisation ratio**

The sign of the shear force is ignored. If  $F_v/P_w > 1.0$ , the capacity is inadequate.

Limitation: Shear buckling check is done in major direction only. For example RHS section in minor direction may be subject to shear buckling but it is not checked in this version.

## **Moment capacity check**

The moment capacity check is done in accordance with clause 4.2.5

### **Applied moment**

The applied moment  $M_x$  or  $M_y$  at the current section about major or minor axis as appropriate

### **Major moment capacity: $M_{cx}$**

The basic moment capacity depends on the local buckling classifications of cross section and the shear utilisation .

Low shear condition

If the plastic shear utilisation does not exceed 0.60 the moment of resistance of the section is calculated according to the formulae in 4.2.5.2.

High shear condition

If the plastic shear utilisation exceeds 0.60 the moment of resistance of the section is calculated according to the formulae in 4.2.5.3

If the ratio  $d/t$  exceeds  $70e$  for a rolled section, or  $62e$  for a welded section, the web should be checked for shear buckling in accordance with 4.4.4 as given below.

The moment of resistance of the section is initially taken as “flange only moment capacity  $M_f$ ” in accordance with 4.4.4.2b)

If the applied moment is greater than  $M_f$ , the web is checked using H.3 for the applied shear combined with any additional moment beyond the flange-only moment capacity  $M_f$

Note that, in the presence of axial force, the flanges-only bending moment capacity is calculated assuming axial force and bending moment are resisted by the flanges only.

To avoid plasticity at working loads, the moment capacity is limited to the value of  $1.5 \cdot p_y \cdot Z_x$  generally and  $1.2 \cdot p_y \cdot Z_x$ , in the case of a simply supported / discontinuous member.

For class 4 section, the reduced design strength  $p_{yr}$  for bending is used at compression fibers when the alternative method of clause 3.6.5 is applicable.

### **Minor moment capacity: $M_{cy}$**

The calculation of moment capacity is similar to that of the major axis, except that the appropriate values are used.


### **Moment utilisation: $M/M_c$**

If  $M_x/M_{cx}$  or  $M_y/M_{cy}$  ratio is more than 1.0, the moment capacity is inadequate.

## Combined checks

### Combined axial and bending check: (Clause 4.8.2.2 or 4.8.2.3 or 4.8.3.2)

This set of results reports on the effects of combining axial load, major and minor axis bending effects at the current section.

 **Note:** It is assumed that the top most fiber is in compression for bending about normal direction and the left most fiber is in compression for bending about lateral direction. The exact fiber stresses are not considered for combined check.

### Simplified method

#### Axial tension utilisation

Axial tension utilisation =  $F_t/P_t$

#### Axial compression utilisation

Axial compression utilisation =  $F_c/P_c$

#### Major moment utilisation

Major moment utilisation =  $M_x/M_{cx}$

#### Minor moment utilisation

Minor moment utilisation =  $M_y/M_{cy}$

### Simple combined effects utilisation ratio

Generally the following relation is used:

$F_t/P_t + M_x/M_{cx} + M_y/M_{cy}$  for axial tension in accordance with 4.8.2.2

$F_c/P_c + M_x/M_{cx} + M_y/M_{cy}$  for axial compression in accordance with 4.8.3.2

### More exact method

#### Plastic section moduli reduced for axial load

If the section classification is 'plastic' or 'compact' and the section shape is I, H, PFC, SHS or RHS, then the plastic moduli  $S_{rx}$  and  $S_{ry}$  are reduced for axial load using the parameters published in [reference<sup>2</sup>](#)

#### Reduced major axis moment capacity

Reduced moment capacity about the major axis:  $M_{rx} = P_y \times S_{rx}$

#### Reduced minor axis moment capacity

Reduced moment capacity about the minor axis:  $M_{ry} = P_y \times S_{ry}$

### More exact utilisation ratio

More exact utilisation is

$M_x \leq M_{rx}$  - for major axis moment only

$M_y \leq M_{ry}$  - for minor axis moment only

$(M_x/M_{rx})^{z1} + (M_y/M_{ry})^{z2} \leq 1$  - for moment about both axis

### Governing utilisation ratio

The governing utilisation for the current section/position is the lesser of the simplified method and more exact method utilisation ratios where the latter is applicable.

### Combined- Shear with axial and moment check:

This check is applicable for plate girders i.e. I sections and box sections with slender web,

If the applied shear  $P_v > 0.6V_w$ , provide that the applied moment does not exceed the "low-shear" moment capacity given in 4.4.4.2a), the web is designed using H.3 for the applied shear combined with any additional moment beyond the "flanges-only" moment capacity  $M_f$  given by 4.4.4.2b).

If the member is also subject to an axial force, reference is also be made to Cl.4.8. The value of  $M_f$  in 4.4.2b) is obtained by assuming that the moment and the axial force are both resisted by the flanges alone, with each flange subject to a uniform stress not exceeding  $P_{yf}$ .

### Combined- Axial, bending and torsion check:

This is a combined elastic stress check in accordance with SCI P 057<sup>4</sup>

#### Normal stress due to major axis bending

The longitudinal direct stress due to major axis bending is calculated as:  $\sigma_{bx} = M_x/Z_x$  as given by equation 2.17

#### Normal stress due to minor axis bending

The longitudinal direct stress due to minor axis bending is calculated as:  $\sigma_{by} = M_y/Z_y$

#### Minor axis bending stress due to major axis moment acting on twisted section

The longitudinal direct stress due to major axis bending together with torsion is calculated as:  $\sigma_{byt} = M_y t / Z_x$  as given by equation 2.18, where  $M_y t$  = angle of twist x  $M_x$ .

#### Normal stress due to warping

The longitudinal direct stress due to warping is calculated as:  $\sigma_w = E \times W_{ns} \times \varnothing''$  as given by equation 2.19 where  $E$  is modulus of elasticity,  $W_{ns}$  is normalized warping function and  $\varnothing''$  is second derivative of twist.

#### Normal stress due to axial force

Normal stress due to axial force  $\sigma_{map} = \text{axial force} / \text{gross area}$

#### Combined normal stress

Combined normal stress =  $\sigma_{map} + \sigma_{bx} + \sigma_{by} + \sigma_{byt} + \sigma_w$

#### Utilisation ratio

Utilisation ratio = Combined normal stress / Design strength

#### Resultant strength utilisation

The greatest utilisation ratio of those of the above checks which are applicable is reported as the resultant strength utilisation

## Web-opening strength checks

Web openings are permitted only in I-section and box section members.

Axial, shear and moment capacity calculations are performed as described in 2.2 above but using the cross section properties of the whole section with the opening deducted. Checks are also done on the individual components of the section above and below the opening in accordance with SCI-P-068<sup>8</sup> as described below:-

### Vierendeel moment check:

#### Top web-flange tee section

##### Effective moment

The effective moment is the major axis moment at the opening.

##### Moment capacity

At the web opening, the plastic moment capacity of the upper web-flange section is calculated using a reduced web thickness ( $t_e$ ) to allow for co-existent shear. For cellular (regular) openings, the upper web-flange moment capacity is taken at the critical section at the angle of 25 degrees from the vertical.

##### Effective axial force

At the web opening, the effective axial force on the tee section is the sum of the 'global' axial force and the Vierendeel force due to the major moment. For cellular openings, the effective axial force is the normal force at the critical section. (i.e. resolving the axial force and shear to the critical section at 25 degrees).

##### Axial capacity

Axial capacity of the top web-flange tee section is calculated using the web thickness reduced for co-existent shear.

##### Utilisation ratio

This top-web flange utilisation is not applicable for web opening. See below overall result utilisation for combined top and bottom web-flanges.

For cellular opening, Utilisation ratio = (Effective axial force/Axial capacity) + (Effective moment/Moment capacity).

#### Bottom web-flange tee section

The above calculations are repeated for the lower tee.

#### Overall results

##### Vierendeel moment

Vierendeel moment = Normal shear \* Width of the opening

##### Vierendeel moment capacity

Vierendeel moment capacity is the summation of upper and lower reduced moment capacity due to axial force and shear.

### Utilisation ratio

It is not applicable for cellular opening because it is individually checked in the above top and bottom web-flange utilisation.

For an isolated web opening, utilisation ratio = Vierendeel moment/Vierendeel moment capacity

### Web-post strength check

This check is applicable only for cellular member.

The maximum Vierendeel moment in a web post is calculated from the formula:-

$$M_{max}/M_e = C_1*(S/D_o) - C_2*(S/D_o)^2 - C_3$$

$$C_1 = 5.097 + 0.1464 * D_o/t - 0.001734*(D_o/t)^2$$

$$C_2 = 1.441 + 0.0625*D_o/t - 0.000683*(D_o/t)^2$$

$$C_3 = 3.645 + 0.0853*D_o/t - 0.00108*(D_o/t)^2$$

Where

$D_o$  = Diameter of the opening in mm

$t$  = thickness of the web

$M_e$  = Elastic bending moment capacity at section A-A =  $Z_e * P_{yw}$

Where:

$$Z_e = t*(S - 0.436*D_o)^2/6$$

Where:

$S$  = center to center spacing of openings in mm

$D_o$  = Diameter of the opening in mm

$D_c$  = distance of the center of the opening from top of the section in mm

### Stress

Web-post stress is calculated for castellated sections only but not applicable for cellular. The maximum bending stress is  $(1.58*V_h)/(t*0.25*D_o)$

Where

$V_h$  is horizontal shear between the two adjacent opening in castellated member

$t$  is thickness of the web

$D_o$  is depth of the opening

### Moment

Maximum moment at section A-A (at a distance 0.9 radius of the opening from the center of the beam in the upper Tee portion) =  $0.9 * \text{Radius of the opening} * \text{Horizontal shear}$

### Strength

Web-post strength is calculated for castellated sections only but not applicable for cellular because for cellular it is expressed as moment capacity.

### **Moment capacity**

Moment capacity is  $M_{max}$  as defined in SCI-P100 section 6.2.5

### **Utilisation ratio**

Utilisation ratio = Moment / Moment capacity for cellular

Utilisation ratio = Stress / Strength for castellated

## **Stability checks**

### **Terms and Definitions**

The following definitions refer to the BS 5950 section X and Y axes. The ESA-PT axes (Y and Z) are shown in brackets.

#### **Member**

Member refers to the buckling system in ESAPT.

#### **Lateral restraints**

Restraints to movement in the local X (Y) direction inhibiting buckling about the Y-Y (Z-Z) local axis

#### **Normal restraints**

Restraints to movement in the local Y (Z) direction inhibiting buckling the X-X (Y-Y) local axis

#### **Lateral segment**

A lateral segment is a portion of the length of member, between consecutive lateral restraints.

#### **Normal segment**

A normal segment is a portion of the length of member, between consecutive normal restraints

At a position, if  $I_{xx} > I_{yy}$ , then normal segment (about local xx) is called major segment and lateral segment (about local yy) is called minor segment, otherwise vice versa.

### **Axial compression buckling**

The buckling resistance under axial compression acting alone is calculated in accordance with clause 4.7.

#### **Normal segment effective length**

A normal segment effective length is that length which with pinned end conditions would have the same axial buckling resistance as the actual length and is derived from the latter by multiplying by the appropriate effective length factor as calculated or input.

#### **Lateral segment effective length**

A lateral segment effective length is that length which with pinned end conditions would have the same axial buckling resistance as the actual length and is derived from the latter by multiplying by the appropriate effective length factor as calculated or input.

#### **Slenderness**

Slenderness is the relevant effective length divided by the relevant radius of gyration. For non prismatic members, an effective value of the radius of gyration 'R<sub>xe</sub>' is calculated from the values at the ends,

middle and quarter point sections:-  $R_{xe} = (R_{x1} + 3R_{x2} + 4R_{x3} + 3R_{x4} + R_{x5})$  For angles, tees, channels and double angles, the various slenderness ratios are calculated according to Code clause 4.7.10 using the relevant radius of gyration and the most unfavourable value is adopted and reported.

### Reduced slenderness

If the web axial class is slender, then reduced slenderness = slenderness\* $\sqrt{A_{eff}/A_g}$ . Otherwise, reduced slenderness is equal to slenderness.

### Maximum slenderness utilisation ratio

The ratio of the actual slenderness and the slenderness limit specified in setup for the relevant axis.

### Strut curve

Strut curve at the position is 'a' or 'b' or 'c' or 'd' as defined in Table 23 and it is used in the computation of Robertson constant.

### Axial buckling strength

Axial buckling strength (stress) is calculated in accordance with BS 5950-1:2000 clause 4.7.5 and Annex C. If, for the relevant axis buckling is prevented by continuous restraint, the value reported for axial strength is the design strength reduced if necessary for local buckling effects.

### Axial force

Applied force is that acting at the section under consideration

### Axial buckling resistances

The resistances (capacity) to axial load buckling about the relevant axes are calculated as per 4.7.4 and reference<sup>2</sup> taking account of the web axial class. Axial buckling resistance (compression resistance) is only based on the slender cross section equation ( $A_{eff} \times p_{cs}$ ) if the value from this equation is greater than the axial load required to make the cross section slender. Otherwise, the compression resistance of a potentially slender section is given as the smallest of the non slender compression resistance and the axial load required to make the section slender.

### Utilisation ratio

The ratio of the applied axial force to the axial compression resistance defines the axial utilisation factor in the relevant axis. If the axial force is tensile, this result is not shown in the output.

## Stability properties for lateral torsional and torsional buckling under major axis moments

The stability properties listed below are calculated for the current position in accordance with Annex B.

1. Buckling parameter (u): ref clause 4.3.6.8 - This parameter is not applicable for Box, T with  $l_{yy} > l_{xx}$ , angle sections.
2. Torsional index (x): ref clause 4.3.6.8
3. Ratio Beta w ( $\beta_w$ ): ref clause 4.3.6.9
  -
4. Gamma (Clause 4.8.3.3): ref clause B.2.3
  -
5. Distance between shear centre of the flanges (hs)
  -

6. Monosymmetry index Psi ( $\Psi$ ): This parameter is applicable only for I with unequal flange (Ref:B.2.4.1), T sections (Ref:B.2.8.2) and unequal angle sections (Ref:B.2.9.3).
- 
7. Flange ratio Eta ( $\eta$ ) : ref: 4.3.6.7
- 
8. Parameter Phi ( $\Phi_b$ ): This parameter is applicable only for Box sections (Ref:B.2.6.1) and angle sections (Ref:B.2.9).

## Lateral-torsional buckling:

Lateral torsional buckling can accrue in minor direction (direction in which lesser moment of inertia) due to the major loading. It is checked in accordance with Clause 4.3.6. Note: Intermediate lateral restraints should be capable of resisting 2.5 % of maximum compression force in the compression flange within the relevant span distributed proportionate to the spacing of Intermediate lateral restraints.

### Effective length

The effective length for lateral-torsional buckling about the minor axis due to major axis bending moments is equal to length between lateral restraints x effective length factor.

### Limiting length $L_m$

The limiting length is the maximum length which will sustain a uniform moment equal to the plastic moment of resistance of the section reduced for the applied axial load calculated per 5.3.5(a). It is only applicable to I and Channel sections which are plastic or compact and without minor axis bending. Equation in 5.3.5 (a) is based on the work by M R Horne (in Safe Loads on I section Columns in Structures Designed by Plastic Theory. Proc ICE vol. 29 1964 pp 137 - 150.) The basic limiting length from 5.3.5(a) is increased, where applicable, to allow for the stabilising effect of a reducing linear moment gradient according to the procedure by Brown in *Steel Designers Manual* 5<sup>th</sup> Edition p 514. If the effective length is not greater than the limiting length, the buckling resistance moment without axial load is equal to the plastic moment of resistance and the buckling resistance moment with the given axial load is equal to the reduced plastic moment of resistance. That is to say the length is too 'stocky' for buckling effects to be significant and it is not necessary to calculate the buckling moment from the slenderness parameters.

### Slenderness ratio

This is the slenderness ratio for buckling about the minor axis under major moment. It involves LTB of the current length between lateral restraints or a proportion thereof defined by the input factors. For non prismatic buckling lengths, the radius of gyration is taken at the section of maximum moment in accordance with Code clause B2.5.

### Uniform moment factor/ [mt]

For uniform segment with normal loading condition, equation of equivalent uniform moment factor for lateral torsional buckling is given in Table 18. Otherwise, for uniform segment with destabilizing loading condition or taper segment, the equivalent uniform moment factor is taken as 1.0. Ref clause 4.3.6.6

### Slenderness correction factor [nt]

For uniform segment, slenderness correction factor [nt] is taken as 1. For member or segment in which the cross section varies along its length, slenderness correction factor [nt] is computed as per B.2.5

### Slenderness factor $\nu$ for LT

This is a correction to the effective length allowing for section monosymmetry and the torsional rigidity of the section. Values are calculated in accordance with B2. For non prismatic lengths the value is based on the properties at the section of maximum major moment in accordance with B3.

### Modified slenderness ratio ( $\lambda_{LT}$ )

For I, channel and all other symmetric open sections, equivalent slenderness is  $u.v.\lambda.(\beta_w)^{0.5}$  as per clause 4.3.6.7 a). Here, for all other symmetric open sections, if the section is low warping ( $H=0$ ), then torsional index is used as defined in I section otherwise torsional index is used as defined in channel section.

For all closed sections, equivalent slenderness is  $2.25.(\Phi_b.\lambda.\beta_w)^{0.5}$  in accordance with clause B.2.6. For plates and flats, equivalent slenderness is computed as  $2.8.(\beta_w.L_E.d/t^2)^{0.5}$  in accordance with clause B.2.7.

Where,

$L_E$  is effective length for LT buckling from 4.3.5,

$d$  is the depth

$t$  is the thickness

For T sections, equivalent slenderness is computed in accordance with clause B.2.8.

a) if  $I_{xx}=I_{yy}$ ; lateral-torsional buckling does not occur and  $\lambda_{LT}$  is zero;

b) if  $I_{yy}>I_{xx}$ ; lateral-torsional buckling occurs about the x-x axis and  $\lambda_{LT}$  is given by;

$$\lambda_{LT} = 2.8(\beta_w.L_E.B / T^2)^{0.5}$$

c) if  $I_{xx}>I_{yy}$ ; lateral-torsional buckling occurs about the y-y axis and  $\lambda_{LT}$  is given by;

$$\lambda_{LT} = u.v.\lambda.(\beta_w)^{0.5}$$

For equal angle sections and all other asymmetric open sections, equivalent slenderness is  $2.25.(\Phi_a.\lambda_v)^{0.5}$  in accordance with clause B.2.9.2. For unequal angle sections, equivalent slenderness is computed as  $2.25.v_a(\Phi_a.\lambda_v)^{0.5}$  in accordance with clause B.2.9.3.

For uniform member, modified slenderness ratio is equal to equivalent slenderness as per clause 4.3.6.7.

For taper member, modified slenderness is taken as slenderness correction factor  $n$  times modified slenderness ratio  $\lambda_{LT}$

### Buckling strength

The bending strength  $P_b$  for resistance to lateral-torsional buckling is determined from Annex B.2.1

### Buckling moment resistance

In general, except for single angles, buckling resistance moment is computed according to 4.3.6.4c). For single angles, buckling resistance moment is computed according to 4.3.8. For non prismatic buckling lengths, the section modulus with local buckling effects is taken at the section of maximum moment in accordance with Code clause B2.5.

### Equivalent uniform moment

The equivalent uniform major axis applied moment on the current buckling length (segment) is equal to the maximum major moment in the major segment  $\times$  equivalent moment factor ( $m$ ). The sign of the moment is ignored.

### Utilisation ratio

Utilisation ratio is equivalent uniform moment divided by buckling moment resistance.

## Minor axis buckling in torsional mode

Torsional buckling (TB) is alternatively referred to as 'distortional buckling' (DTB), especially in bridge and composite beam applications. However, the term adopted in BS 5950:2000 part 1 is used here. Torsional buckling entails the lateral movement of an unrestrained flange which is in compression whilst the other flange is held in position by intermediate restraints so that the section twists. The ends of the torsional buckling length are defined either by direct physical restraints to the compression flange or by 'virtual restraints' arising by virtue of the unrestrained flange going into a tension zone opposite a restraint to the other flange. Torsional buckling lengths are therefore determined not only by the position and connection details of the lateral restraints but also by the stress conditions at the restraints. The calculations are generally in accordance with Appendix G of BS 5950:2000 part 1 with some interpretation from background sources and where specific guidance is lacking, (e.g. for minor axis bending effects).

Torsional segment is the member or portion of the member, between adjacent points that are laterally restrained at compression flange. Also the segment should have at least one intermediate tension flange restraint to develop torsional mode of buckling.

Note: Lateral restraints should be capable of resisting 2.5% of maximum compression force in the compression flange within the relevant span distributed proportionate to the spacing of restraints.

### Effective length

The effective length for torsional buckling is taken to be the actual potential buckling length between effective compression flange restraints as defined in G.2.3. No effective length or depth factors are applied.

### Taper factor $c$

For uniform member lengths  $c = 1.0$ . For haunched and tapered lengths,  $c$  is calculated in accordance with G.3.3 to allow for the length and depth of the taper.

### Limiting length $L_s$

For the particular case of I-section members without minor axis bending and for plastic conditions, Appendix G defines the criterion for torsional stability whether the potential buckling length exceeds the 'limiting length' for the current axial load and moment distribution. The program calculates the basic limiting length 'Lk', as defined in G.3.3.3 which is that length of the current section between full lateral restraints and with intermediate tension flange restraints which would be just stable under a uniform moment equal to the simple plastic moment of resistance. The equation for Lk in G.3.3.3 was developed by Horne, Shakir-Khalil, and Akhtar (The stability of tapered and haunched beams. Proc.ICE part 2 1979, 67, Sept. pp 677-694.) The basic limiting length is modified by the slenderness correction factor 'nt' which allows for non uniformity of the moment diagram and the axial load as noted above and the taper factor 'c'.

For 'plastic' conditions, if the effective length 'Lt' is greater than the limiting length 'Lk/(c\*nt)', then the length is incapable of sustaining the applied moment and axial load distribution allowing for plastic conditions. If the effective length is not greater than the limiting length, the buckling resistance moment without axial load is equal to the plastic moment of resistance and the buckling resistance moment with the given axial load is equal to the reduced plastic moment of resistance. That is to say the length is too 'stocky' for buckling effects to be significant and it is not necessary to calculate the buckling moment from the slenderness parameters.

### Slenderness ratio

Slenderness ratio is equal to the effective length divided by the radius of gyration in minor direction. For non prismatic members, an effective value of the radius of gyration 'Rxe' is calculated from the values at the ends, middle and quarter point sections:-

$$Rxe = (Rx_1 + 3Rx_2 + 4Rx_3 + 3Rx_4 + Rx_5)$$

### Slenderness ratio ( $\lambda_{TC}$ )

The minor axis equivalent slenderness for torsional buckling under axial load is derived from the basic minor slenderness ratio for the buckling length by application of the correction factor 'y', calculated in accordance with G.2.3 to allow for the presence of tension flange restraints, the torsional stiffness of the section and eccentricity of the restraint axis.

### **Compression strength**

The minor axis axial buckling strength is calculated from the slenderness  $\lambda_{TC}$  and the design strength  $p_y$  reduced if necessary for local buckling using 4.7.4 and 5 and Appendix C.

### **Compression resistance**

The minor axis buckling resistance is calculated as the product of the gross section area and the buckling strength (stress). For non prismatic members the area varies with the position.

### **Axial compression force**

For uniform member lengths, the critical compression force is taken to be the maximum occurring within the current length. For non prismatic lengths calculations are made for specific positions and the compression force is that operating at the current position.

### **Axial compression utilisation ratio**

Axial compression utilisation ratio is axial force divided by compression resistance. The axial utilisation factor indicates the extent to which axial compression is critical and consequently whether there is capacity available for bending. If the axial force is tensile, then this parameter is zero.

### **Uniform moment factor [mt]**

For uniform members or segments under linear moment gradient, the value of uniform moment factor  $m_t$  specified in table G.4.2, depends on the value of the end moment ratio. For all other cases,  $m_t$  is taken as 1.

### **Slenderness correction factor [nt]**

For taper segment and non-uniform moment in a uniform segment, slenderness correction factor will be calculated in accordance with G.4.3.

### **Slenderness factor v for TB**

The torsional slenderness factor 'vt' is calculated according to G.2.4.1 to allow for the presence of tension flange restraints, the torsional stiffness of the section and the eccentricity of the restraint axis.

### **Slenderness ratio ( $\lambda_{TB}$ )**

The minor axis equivalent slenderness ratio for torsional buckling under major axis moment is derived from the basic slenderness ratio of the buckling length ' $L_y/r_y$ ' by application of the multiplying factors: 'nt', 'u', 'vt' and 'c'. The slenderness correction factor 'nt' and taper factor 'c' are as noted above. The section buckling parameter 'u' is calculated in accordance with 4.3.6.8.

### **Buckling strength**

The bending strength  $P_b$  for resistance to torsional buckling is determined from B.2.1

### **Buckling moment resistance**

If the effective length ' $L_e$ ' does not exceed the limiting length for plastic action ' $L_k/(c.nt)$ ', the major axis buckling resistance moment equals the plastic moment of the section. If the limiting length is exceeded, the major axis torsional buckling resistance moment is calculated from the equivalent slenderness ' $L_{tb}/r_y$ ' and the design strength ' $p_y$ ' reduced for local buckling, if applicable.

### **Equivalent uniform moment**

For uniform member lengths the equivalent uniform major axis applied moment is derived from the maximum moment in the length causing compression in the unrestrained flange 'Mx' by application of the equivalent moment factor 'mt' as noted above. For non prismatic member lengths, the calculations are carried out for specific positions rather than for the whole length so 'm' factors are not applicable. The equivalent major moment is then the actual moment acting at the position allowing for any adjustment caused by the eccentricity of any axial force applied on the main member axis relative to the section neutral axis.

**Major moment utilisation:  $mt.Mx/Mbt$**

The ratio of the equivalent uniform major axis moment to the torsional buckling moment of resistance indicates the criticality of this effect.

**Minor axis resistance moment:  $py.Zy$**

Minor axis moments are not mentioned in Appendix G, presumably because in many cases the presence of the intermediate lateral restraints which allow torsional buckling to be critical simultaneously prevent moments arising in the lateral plane. However it is possible for minor axis moments to arise due to lateral loads applied between restraints. Should this be the case, the program extrapolates the treatment provided in 4.8.3.3.1 for the interaction of lateral moments with lateral buckling to the case of torsional buckling. The minor axis resistance moment is therefore taken to be the elastic yield moment: 'py.Zy'.

**Equivalent minor axis moment:  $m.My$**

The equivalent uniform minor axis moment is taken as the product of the maximum minor axis moment in the length and the uniform moment factor derived as noted for lateral buckling. For non prismatic member lengths, the calculations are carried out for specific positions rather than for the whole length so 'm' factors are not applicable. The equivalent major moment is then the actual moment acting at the position.

**Minor axis moment utilisation:  $m.My/py.Zy$**

The minor axis utilisation is simply the ratio of the equivalent uniform applied moment to the minor resistance moment.

**Combined Utilisation ratio**

The utilisation factor for combined effects is the sum of the individual utilisation factors for axial load, major and minor bending.

## Combined buckling under axial compression and moment

**Axial compression buckling (Axial compression with moment)**

This check is similar to the above 'Axial compression buckling (Axial compression alone)' check with local buckling effects of combined axial and bending. i.e. cross section classification is used instead of web axial class.

**Combined- Axial moment buckling check**

Axial moment buckling check is combined lateral segment in the current position and the normal segment in the current position in accordance with Clause 4.8.3.3.

**Uniform moment factor [mLT]**

The value of mLT for lateral torsional buckling is calculated from major axis moments over the minor segment as equation given in table 18.

**Uniform moment factor [mx]**

The value of  $m_x$  for major axis flexural buckling is calculated from major axis moments over the minor segment as equation given in table 26.

#### **Uniform moment factor [ $m_y$ ]**

The value of  $m_y$  for minor axis flexural buckling is calculated from minor axis moments over the minor segment as equation given in table 26.

#### **Uniform moment factor [ $m_{yx}$ ]**

The value of  $m_{yx}$  for lateral flexural buckling is calculated from minor axis moments over the major segment as equation given in table 26.

#### **Normal moment**

For uniform member, normal moment is the maximum normal moment in the normal segment. For taper member, normal moment at the current position is taken. Should this be the case, the program extrapolates the treatment provided in G.2.2 for the combined torsional buckling check.

#### **Lateral moment**

For uniform member, lateral moment is the maximum minor moment in the minor segment. For taper member, normal moment at the current position is taken. Should this be the case, the program extrapolates the treatment provided in G.2.2 for the combined torsional buckling check.

#### **Simple method**

##### **Normal moment capacity**

Normal moment capacity is limited to elastic for class 1 and 2 section and a slender property is taken for class 4 section. Should this be the case, the program extrapolates the treatment provided in 4.8.3.2 for combined axial moment local capacity. For taper member, section properties are taken from the current position.

##### **Lateral moment capacity**

Lateral moment capacity is limited to elastic for class 1 and 2 sections and a slender property is taken for class 4 section. Should this be the case, the program extrapolates the treatment provided in 4.8.3.2 for combined axial moment local capacity. For taper member, section properties are taken from the current position.

##### **First utilisation ratio Simple**

$F_c/P_c + m_x.M_x/M_{bx} + m_y.M_y/M_{by}$ . The axial, major and minor axis utilisations are summed per the 'simplified' approach of 4.8.3.3.1.

##### **Second utilisation ratio Simple**

$F_c/P_{cy} + m_{LT}.M_{LT}/M_b + (m_y.M_y)/(P_y.Z_y)$ . Axial utilisations in minor segment, lateral torsional buckling utilisations and minor axis segment utilisations are summed per the 'simplified' approach of 4.8.3.3.1.

##### **Governing simple interaction**

Governing simple interaction is higher of the first and second utilisation.

#### **More exact method**

##### **Utilisation ratio for major axis buckling**

In general, Utilisation ratio for major axis buckling is equal to  $F_c/P_{cx} + m_x.M_x/M_{cx}(1 + 0.5.F_c/P_{cx}) + 0.5.m_{yx}.M_y/M_{cy}$  as clause 4.8.3.3.2 C). For member with moments about the major axis only, i.e.  $M_y=0$ , this utilisation can be called in-plane buckling. For member with moments about the minor axis only, i.e.  $M_x=0$ , this utilisation can be called out-of-plane buckling.

### Utilisation ratio for lateral torsional buckling

In general, Utilisation ratio for lateral torsional buckling is equal to  $F_c/P_{cy} + m_{LT} \cdot M_{LT}/M_b + m_y \cdot M_y/M_{cy}(1 + F_c/P_{cy})$  as clause 4.8.3.3.2 C). For member with moments about the major axis only, i.e.  $M_y=0$ , this utilisation can be called out-of-plane buckling. For member with moments about the minor axis only, i.e.  $M_x=0$ , this utilisation can be called in-plane buckling.

### Utilisation ratio for interactive buckling Exact

$$m_x \cdot M_x(1+0.5(F_c/P_{cx})) / M_{cx}(1-F_c/P_{cx}) + m_y \cdot M_y(1+F_c/P_{cy}) / M_{cy}(1-F_c/P_{cy})$$

### Governing exact interaction

Governing exact interaction is higher of the above three utilisations.

### Resultant utilisations

Resultant utilisation is minimum utilisation of the governing simple interaction and governing exact interaction.

## Buckling under combined axial force, bending and torsion moments

### Assumptions

1. SCI P 057 is extended to support curved member check along with SCI P 281
2. In this, it is assumed that axial utilisation ratio is additive to equation 2.23 of SCI P 057 for combined axial bending and torsion.
3. The current scope is limited to closed sections and sections of low warping rigidity (EH). This includes all closed sections, angle sections and Tee sections.

Though BS5950:2000 identifies the internal effects as shear and moment, SCI P 057 identifies the effects in terms of stress. For example BS5950:2000 identifies the plastic shear capacity as  $0.6 \cdot A_v \cdot P_y$  compared with the shear force, but SCI P 057 identifies the elastic shear stress as  $V \cdot Q_w / I \cdot t$  compared with  $0.6 \cdot P_y$ . So the program caters to this stress approach only for combined axial force, bending and torsion moments checks.

Stresses listed below are produced in a member by torsion:

1. Shear stress in web due to pure torsion, reference<sup>2</sup> eq. 2.8 or 2.9
2. Shear stress in flange due to pure torsion, reference<sup>2</sup> eq. 2.8 or 2.9
3. Shear stress in web due to warping torsion, reference<sup>2</sup> eq. 2.13
4. Shear stress in flange due to warping torsion, reference<sup>2</sup> eq. 2.13.

Stresses mentioned below are produced in a member due to plane bending:

1. Shear stress in web due to normal bending, reference<sup>2</sup> eq. 2.15
2. Shear stress in flange due to normal bending, but this value is not taken into account, because the entire normal shear is taken by web only.
3. Shear stress in web due to lateral bending, but this value is not taken into account, because the entire lateral shear is taken by flange only.
4. Shear stress in flange due to lateral bending, reference<sup>2</sup> 2.16

### Combined shear stress acting in web, reference<sup>2</sup> eq. 2.25

It is shear stress in web due to pure torsion + shear stress in web due to normal bending +  $(1 + 0.5 \cdot M_x/M_b)$

### Combined shear stress acting in flange, reference<sup>2</sup> eq. 2.25

It is shear stress in flange due to pure torsion + shear stress in flange due to normal bending +  $(1 + 0.5.Mx/Mb)$

### **Combined shear utilisation**

Combined shear utilisation is larger of combined shear stress acting downwards and acting left to right divided by  $0.6 \cdot P_y$

### **Combined axial, bending and torsion utilisation**

Axial, bending and torsion utilisation, reference<sup>2</sup> eq. 2.23

## **Combined minor axis buckling in torsional mode**

### **Utilisation ratio for torsional buckling under axial force and major axis moment**

It is  $F_c/P_c + m_t M_x / M_b$  in accordance with G.2

### **Utilisation – minor axis moment**

$m_y M_y / P_y Z_y \leq 1$

In general if torsional buckling situation is possible there should be no minor axis effects because they would be transmitted to the lateral restraints and bending between restraints would be v small. However in many cases source frame analysis will not model restraints and minor axis moments may arise due to various load and stiffness effects.

In order to cater for the above the program includes minor axis utilisation in the utilisation for TB [Annex G] check above on simple linear interaction basis.

The expression for torsional buckling check as stated in Annex G is extended considering minor axis moment utilization ratio (similar to the combined buckling resistance check) as given below,

### **Combined utilisation ratio**

$F_c/P_c + m_t M_x / M_b + m_y M_y / P_y Z_y \leq 1$

It is done for all TB segments and then the segment with the greatest U is the critical one

### **Resultant stability utilisation**

This is critical of all the above checks.

## **Serviceability Check**

### **Normal deflection**

#### **Normal deflection**

Lateral deflection at the current position.

#### **Normal deflection limit**

It is the maximum allowable deflection in normal direction. This is defined as a *minimum* span/deflection ratio.

#### **Utilisation ratio for normal flexural deflection**

Utilisation ratio is the normal deflection at the current position divided by the normal deflection limit specified.

## Lateral deflection

### Lateral deflection

Lateral deflection at the current position.

### Lateral deflection limit

It is the maximum allowable deflection in lateral direction. This is defined as a *minimum* span/deflection ratio.

### Utilisation ratio for lateral flexural deflection

Utilisation ratio is the lateral deflection at the current position divided by the lateral deflection limit specified.

## Twist

### Twist

Twist at the current position.

### Twist limit

It is the maximum allowable twist about the axis of the member.

### Utilisation ratio for twist

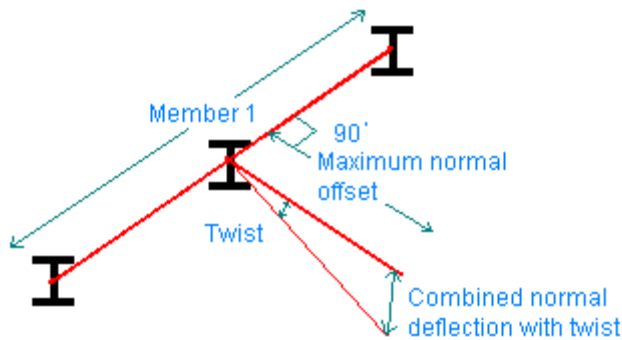
Utilisation ratio is the twist at the current position divided by the twist limit specified.

## Combined flexural deflection with twist

### Deflection with twist limit

For each member type the user can specify the maximum combined deflection at an offset from the member axis due to flexural and torsional effects. This is also defined as a *minimum* span/deflection ratio.

### Maximum normal offset:



The maximum normal offset is the distance perpendicular to the member axis to the point at which the deflection is required eg, face of wall.

#### Calculation for actual deflection with twist:

Actual deflection with twist = flexural deflection + offset times angle of twist

#### Calculation for deflection with twist limit:

Deflection with twist limit = span / input specified in the set up of relative deformation.

#### Utilisation for deflection with twist limit:

Utilisation for deflection with twist limit = actual deflection with twist / deflection with twist limit

## Curved member design

### Introduction

The scope is limited to circular and parabolic curve types in any 2D plane for this version.

Curved member design check is based on the procedure mentioned in reference<sup>5</sup> and reference<sup>6</sup>. The design check differs for members curved in elevation and in plan. A member curved in elevation is defined such that member and plane of loading are in the same plane. If the plane of loading is perpendicular to plane of curved member then it is said to be a curved member in plan. As the design procedure (in accordance with reference<sup>5</sup>) depends on whether a member is curved in plan or in elevation, we must classify the curve as either curved member in plan or in elevation.

According to the current scope, non-straight design members must be loaded either in-plane or out-of plane but not both in any one load combination.

### Design procedure for members curved in elevation

For curved member in elevation, the reduced design strength depends upon the curvature of the member. Hence design strength is calculated at a position with maximum  $Mx/R$  value where,  $Mx$  is major moment and  $R$  is radius of the arc.

- **Reduced design strength calculation  $P_y$**

For the member curved in elevation, the design strength ( $P_y$ ) is reduced which depends on the geometry of the curve (specifically radius of curvature at the position and the convexity or concavity of the flanges which in turn depends on the location of the centre of the curve).

- **Local capacity checks**

**Moment capacity check**

Reduced design strength is used in major and minor moment capacity computation for member curved in elevation.

**Combined axial compression and bending check**

It is checked using 4.8.3.2 of reference<sup>1</sup>, where appropriate, the value of compression capacity,  $M_{cx}$  and  $M_{cy}$  is computed with  $P_{yd}$ . For all other local capacity check, as given in reference<sup>5</sup>, it is desirable to use the same design process for curved members as for straight members.

- **Stability check**

**Axial compression buckling check**

For compression buckling check, as given in SCI P 281, it is desirable to use the same design process for curved members as for straight members except as noted below

1.  $P_{yd}$  is used instead of  $P_y$
2. Effective length computation is used as given below
  - a. Effective lengths in plane: It is calculated in accordance with section 6.4.2 of reference<sup>5</sup>.
  - b. Effective lengths out of plane: It is calculated in accordance with section 6.4.3 of reference<sup>5</sup>.

**Lateral torsional buckling check**

Effective length factor for the curved member in elevation is defined in a different way when compression flange of the member is convex. (from reference<sup>5</sup>, page No. 37) and all subsequent design processes are the same as a straight member but reduced design strength  $P_{yd}$  is used.

**2.2.2.4 Combined axial load and bending buckling check**

It is checked using 4.8.3.3.1 of reference<sup>1</sup>, where appropriate, the value of compression capacity,  $M_{cx}$  and  $M_{cy}$  is computed with  $P_{yd}$ .

**Design procedure for members curved in plan**

As an alternative to the approach mentioned in reference<sup>5</sup> the below approach mentioned in reference<sup>4</sup> is used for curved members in plan. The current scope is limited to closed sections and sections of low warping rigidity (EH). This includes all closed sections, angle sections and Tee sections.

1. Design procedure considers additional torsional and warping effects (only in case of open cross-section).
2. In classification, section with  $b/T$  ratio more than  $8.5 \cdot \epsilon$  is not allowed.
3. Reduced design strength doesn't depend on the curvature of the member. In other words, in most common cases, out-of-plan stress due to curvature ( $\sigma_2$ ) is not significant. Hence  $P_{yd}$  is computed as defined in equation 6.1 of reference<sup>5</sup> is used with  $\sigma_2$  as zero.
4. Reduced design strength is used for curved members in plan as for in elevation.

## Numerical section

Numerical section has cross-section properties and no specific key-dimensions. Design procedure using numerical section requires some conservative assumptions in the absence of key dimensions.

Following are the basic assumptions in the design of numerical section:

1. Axial compression class is assumed to be non-slender because of difficulty in calculating effective properties. And the cross section class set to be class 3.
2. Design strength is calculated as  $Y_s$  if  $Y_s < U_s/1.2$  otherwise consider  $U_s/1.2$  as design strength.
3. Numerical section is assumed as unsymmetrical about both the principle axis and with large torsional rigidity as compared to warping rigidity (warping deformations are assumed negligible)
4. Strut curve "c" is considered for axial compression in case of major and minor axis flexural buckling check.
5. Limiting length for lateral-torsional buckling and torsional buckling check is assumed to be zero.
6. Web is considered non-slender and shear-buckling check is not performed.
7. In stability property and slenderness ( $\lambda_{LT}$ ) calculation, following conservative assumptions are made.

For rolled sections, slenderness factor  $u = 0.9$

For welded sections, slenderness factor  $u = 1.0$

Torsional index  $x = 1.132 * ((Ag * H) / (I_y * J))^{0.5}$

Factor  $v = 1 / (1 + 0.05 * (\lambda / x)^2)^{0.25}$

$\lambda_{LT} = u * v * \lambda * (\beta_w)^{0.5}$

Factors  $y$  in  $\lambda_{TC}$  and factor  $v_t$  in  $\lambda_{TB}$  are assumed to be 1 (since "a" is not defined "vt" cannot be calculated)

8. A numerical section is always assumed to be uniform and the taper factor "c" is assumed to be 1.
9. For numerical sections the more exact method of combined axial and bending buckling check is not applicable.
10. Curved members cannot be designed using numerical sections.
11. Numerical sections cannot be used for a member with web-opening.

## Supported section

The table below shows the cross sections supported for a particular check.

(x) mark indicates the cross section applicable for the check.

The column numbers represent the following checks

- (1) – All checks expect the following (2 to 6)
- (2) – Moment capacity check at high shear condition
- (3) – Shear buckling check
- (4) – Torsion check
- (5) – Web opening check
- (6) – Cellular member check

Descriptions	ESA Name	(1)	(2)	(3)	(4)	(5)	(6)
Profile Library							
Symmetric I (UB, UC, etc..)	I	x	x	x		x	x
Asymmetric I	PPL	x	x			x	
Rectangular Hollow section	RHS	x	x	x	x	x	
Circular Hollow section	CHS	x			x		
Angle section	L	x	x		x		
Channel section	U	x	x				
T section	T	x	x				
Built in beams	THQ	x					
	SFB	x					
Closed	Box web	x	x		x		
	2U+2PI box	x	x		x		
	I+2PI	x	x		x		
	Box fl	x	x		x		
	2L Box	x	x		x		
	4L Box	x	x		x		
	2U Box	x			x		
Geometric shapes	I ng	x	x			x	
	Tg	x	x				
	Lg	x	x				
	Ug	x	x				
	Tube	x			x		
Thin walled Geometric	--						
	I	x	x	x		x	
	Asym I	x	x			x	
	RHS	x	x	x	x	x	
	CHS	x			x		
	angle	x	x		x		
	Channel	x	x				
	T	x	x				
Haunch	I+lvar	x					
	lw+lvar	x					
	lw+lvar	x					
	I var	x					
	I+lvar	x					

	I+2I var	x					
	IvarCelluated	x					x
Pairs	2I	x	x				
	2Uc	x	x				
	2Uo	x	x				
	2LT	x	x				
	2LU	x	x				
	4LU	x	x				
	2LTn	x	x				
	2LU <sub>n</sub>	x	x				
Sheet welded	--						
Welded	I+PL	x	x				
	U+Plu	x	x				
	U+Pl <sub>d</sub>	x	x				
	I+U <sub>d</sub>	x	x				
	IX	x	x				
	I + I <sub>r</sub>	x	x				
	I+2PLU <sub>d</sub>	x	x				
	I+T <sub>I</sub>	x	x				
	U + I <sub>l</sub>	x					
	U + I <sub>r</sub>	x	x				
General	--						
Numeric	--	x					

**Note:** All other cross sections are considered as numerical sections for design check

## References

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