Tekla Structural Designer 2021

Design Codes Reference: British Standards

May 2021

Contents

1 British Standards

1.1 Loading (British Standards)

This handbook provides a general overview of how loadcases and combinations are created in Tekla Structural Designer when a British Standards (BS) head code is applied. The Combination Generator for BS loading is also described.

Click the links below to find out more:

- Loadcases (page 3)
- Combinations (page 6)

Loadcases (British Standards)

Click the links below to find out more:

- Loadcase types (page 3)
- Self weight (page 4)
- Imposed and roof imposed loads (page 5)
- Wind loads (page 6)

Loadcase types (British Standards)

The following loadcase types can be created:

Loadcase Type	Calculated Automatically	Include in the Combination Generator	Imposed Load Reductions	Pattern Load
self weight (beams, columns and walls)	yes/no	yes/noI	N/A	N/A
slab wet	yes/no	N/A	N/A	N/A
slab dry	yes/no	yes/no	N/A	N/A
dead	N/A	yes/no	N/A	N/A
imposed	N/A	yes/no	yes/no	yes/no
roof imposed	N/A	yes/no	N/A	N/A
wind	N/A	yes/no	N/A	N/A
snow	N/A	yes/no	N/A	N/A
snow drift	N/A	yes/no	N/A	N/A
temperature	N/A	N/A	N/A	N/A
settlement	N/A	N/A	N/A	N/A
seismic	N/A	yes	N/A	N/A

As shown above, self weight loads can all be determined automatically. However, other gravity loadcases have to be applied manually as you build the structure.

Self weight (British Standards)

Self weight - excluding slabs loadcase

Tekla Structural Designer automatically calculates the self weight of the structural beams/columns for you. The **Self weight - excluding slabs** loadcase is pre-defined for this purpose. Its loadcase type is fixed as “Selfweight”. It cannot be edited and by default it is added to each new load combination.

Self weight of concrete slabs

Tekla Structural Designer expects the wet and dry weight of concrete slab to be defined in separate loadcases. This is required to ensure that members are designed for the correct loads at construction stage and post construction stage.

The **Slab self weight** loadcase is pre-defined for the dry weight of concrete post construction stage, its loadcase type is fixed as “Slab Dry”.

There is no pre-defined loadcase for the wet weight of concrete slab at construction stage, but if you require it for the design of any composite beams in the model the loadcase type should be set to “Slab Wet”.

Tekla Structural Designercan automatically calculate the above weights for you taking into account the slab thickness, the shape of the deck profile and wet/dry concrete densities. It does not explicitly take account of the weight of any reinforcement but will include the weight of decking. Simply click the **Calc Automatically** check box when you create each loadcase. When calculated in this way you can’t add extra loads of your own into the loadcase.

If you normally make an allowance for ponding in your slab weight calculations, Tekla Structural Designer can also do this for you. After selecting the composite slabs, you are able to review the slab item properties - you will find two ways to add an allowance for ponding (under the slab parameters heading). These are:

- as a value, by specifying the average increased thickness of slab
- or, as a percentage of total volume.

Using either of these methods the additional load is added as a uniform load over the whole area of slab.

Imposed and roof imposed loads (British Standards)

Imposed load reductions

Reductions can be applied to imposed loads to take account of the unlikelihood of the whole building being loaded with its full design imposed load. Reductions can not however be applied to roof imposed loads.

Imposed loads are only automatically reduced on:

- Columns of any material
- Concrete walls, mid-pier or meshed

Tekla Structural Designer does not automatically apply imposed load reductions to floors. For steel beams, concrete beams, slabs and mats it is however possible to define the level of imposed load reduction manually via the beam/slab item properties.

This is particularly relevant for the design of transfer beams/slabs:

- The imposed load reduction for beams, slabs and mats is intended to work with loads applied from columns acting on the beam or slab when the slab is acting in transfer or for a mat foundation supporting a column. (The theory being that if you want to design the columns for the reduced axial load, you should also design the supporting member for the reduced axial load applied by the column.)
- The engineer would need to work out the reduction of the axial load in the column and apply this as a the reduction percentage, i.e. if the raw axial load in the column is 100kN and the reduced load is 60kN, the reduction is

40%. You would than apply the 40% reduction to the transfer beam/slab or mat as well.

- The reduction is not applied to loads for analysis - it is a post-analysis process which does not affect the analysis results. It does not get applied solely to the imposed load applied directly to the beam or slab panel, but instead is applied to the design moment used in the beam/slab or mat design process.

Wind loads (British Standards)

The BS 6399-2 Wind wizard...

NOTE The **Wind Wizard** used for automatic wind loadcase generation is fully described in the Wind Modelling Engineer's Handbook.

The **Wind Wizard...** is run to create a series of static forces that are combined with other actions due to dead and imposed loads in accordance with BS6399-2:1997.

The following assumptions/limitations exist:

- The shape of the building meets the limitations allowed for in the code.
- It must be a rigid structure.
- The structure must be either enclosed or partially enclosed.
- Parapets and roof overhangs are not explicitly dealt with.

For further information on the wind loading capabilities of Tekla Structural Designer refer to the Wind Modelling Engineer's Handbook.

Simple wind loading

If use of the **Wind Wizard** is not appropriate for your structure then wind loads can be applied via element or structure loads instead.

Combinations (British Standards)

Once your loadcases have been generated as required, you then combine them into load combinations; these can either be created manually, by clicking **Add...** - or with the assistance of the Combinations Generator, by clicking **Generate...**

NOTE For the British Standard codes we are assuming that the wind load applied in manually defined combinations, or via the combination generator, satisfies the minimum horizontal load requirement (BS5950 Cl 2.4.2.3 (1% of factored dead load) and BS8110 Cl 3.1.4.2 (1.5% characteristic dead weight)). If this is not the case, i.e. the wind load is less than the minimum proportion of dead load specified in the code, then you need to consider manually creating a minimum horizontal load combination.

Click the links below to find out more:

- Manually defined combinations (page 7)
- Notional horizontal forces (NHFs) (page 7)
- Combination generator (page 7)
- Combination classes (page 8)

Manually defined combinations (British Standards)

As you build up combinations manually, the combination factors are automatically adjusted as loadcases are added and removed from the combination.

Notional horizontal forces (NHFs) (British Standards)

NHF's are automatically derived from the loadcases within the current combination, their magnitude being calculated in accordance with BS5950 cl 2.4.2.3 as 0.5% of the factored vertical load that passes through any beam/column intersection in the structure.

NOTE BS8110 cl 3.1.4.2 has a requirement for notional horizontal load "NHL" This does NOT equate to the NHF requirement described above. The calculation of "NHL" as defined in BS8110 is beyond scope in the current version of Tekla Structural Designer.

They are applied to the structure in the building directions 1 and 2 as follows:

- NHF Dir1+
- NHF Dir1-
- NHF Dir2+
- NHF Dir2-

The net result is that any combination is able to have up to 2 Notional Loads applied within it - one from Dir1 (+ or -) and one from Dir2 (+ or -). Note however, that Dir1+ can not be added with Dir1- (and similarly Dir2+ can not be added with Dir2-).

Combination generator (British Standards)

Accessed via the **Generate...** command, this automatically sets up combinations for both strength and serviceability.

Combination generator - Combinations

The first page of the generator lists the combinations applicable (with appropriate strength factors).

The following basic load combinations are created:

- 1.4 (Dead) + 1.6 (Imposed or Snow)
- 1.2 (Dead) + 1.2 (Imposed or Snow) + 1.2 (Wind)
- 1.0 (Dead) + 1.4 (Wind)

NOTE Temperature and settlement loadcase types are not included in the **Generate...** command - these need to be added manually.

The combination names are generated automatically.

Combination generator - Service

This page indicates which combinations are to be checked for serviceability and the factors applied.

The following basic load combinations are created:

- 1.0 (Dead) + 1.0 (Live or Snow)
- 1.0 (Dead) + 0.8 (Live or Snow) + 0.8 (Wind)
- 1.0 (Dead) + 1.0 (Wind)

Combination generator - NHF

The last page is used to set up the notional horizontal forces. You can specify NHF's and factors in each of four directions. For each direction selected, a separate NHF combination will be generated.

Any combination with wind in is automatically greyed.

Click **Finish** to see the list of generated combinations.

Combination classes (British Standards)

Having created your combinations you classify them as: Construction Stage, Gravity, Lateral, or Modal Mass.

NOTE If generated via the Combinations generator they are classified for you automatically.

Then (where applicable) you indicate whether they are to be checked for strength or service conditions, or both. You also have the option to make any of the combinations inactive.

Construction stage combination (British Standards)

A Construction Stage load combination is only required for the purpose of designing any composite beams within the model. It is distinguished from other combinations by setting its “Class” to Construction Stage. Typically this combination would include a loadcase of type “Slab Wet”, (not “Slab Dry”), other loadcases being included in the combination as required.

NOTE The Slab Wet loadcase type should not be included in any other combination.

Gravity combination (British Standards)

These combinations are considered in both the Gravity Sizing and Full Design processes.

They are used in the Gravity Sizing processes as follows:

- Design Concrete (Gravity) - concrete members in the structure are automatically sized (or checked) for the gravity combinations
- Design Steel (Gravity) - steel members in the structure are automatically sized (or checked) for the gravity combinations.
- Design All (Gravity) - all members in the structure are automatically sized (or checked) for the gravity combinations.

They are also used during the Full Design processes as follows:

- Design Concrete (All) - concrete members in the structure are automatically sized (or checked) for the gravity combinations.
- Design Steel (All) - steel members in the structure are automatically sized (or checked) for the gravity combinations.
- Design All (All) - all members in the structure are automatically sized (or checked) for the gravity combinations.

Lateral combinations (British Standards)

These combinations are **not** used in the Gravity Sizing processes.

They are used during the Full Design processes as follows:

- Design Concrete (All) - concrete members in the structure are automatically sized (or checked) for the lateral combinations.
- Design Steel (All) - steel members in the structure which have not been set as Gravity Only are automatically sized (or checked) for the lateral combinations.
- Design All (All) - all concrete members and all steel members which have not been set as Gravity Only are automatically sized (or checked) for the lateral combinations.

Modal mass combinations (British Standards)

For modal analysis, you are required to set up specific “modal mass” combinations. Provided these combinations are active they are always run through the modal analysis.

NOTE It is always assumed that all loads in the loadcases in the combination are converted to mass for modal analysis. You are permitted to add lumped mass directly to the model.

1.2 Steel design to BS 5950

Tekla Structural Designer designs steel members and composite members to a range of international codes. This reference guide specifically describes the design methods applied when the steel design and composite design resistance codes are set as BS 5950-1 and BS 5950-3.1 respectively.

Unless explicitly noted otherwise, all clauses, figures and tables referred to are from BS 5950-1:2000 (Ref. 2); apart from the Composite Beam section, within which references are to BS 5950-3.1:2010 (Ref. 1) unless stated.

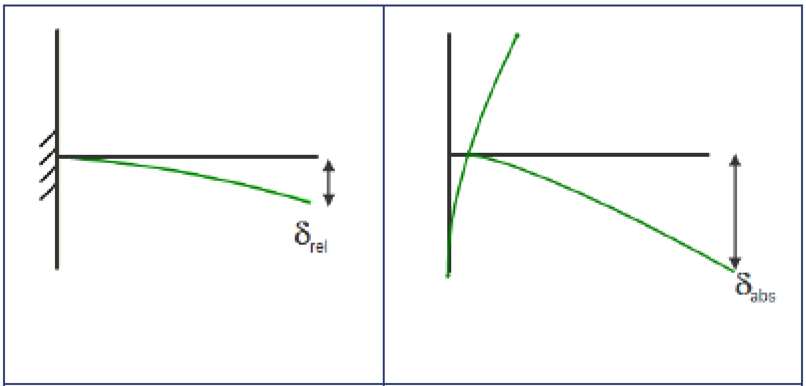
Click the links below to find out more:

- Basic principles (page 10)
- Steel beam design (page 11)
- Composite beam design (page 21)
- Steel column design (page 32)
- Steel brace design (page 40)
- Steel single, double angle and tee section design (page 40)

Basic principles (BS 5950)

Deflection checks

Tekla Structural Designer calculates both ***relative*** and ***absolute*** deflections. Relative deflections measure the internal displacement occurring within the length of the member and take no account of the support settlements or rotations, whereas absolute deflections are concerned with deflection of the structure as a whole. The absolute deflections are the ones displayed in the structure deflection graphics. The difference between ***relative*** and ***absolute*** deflections is illustrated in the cantilever beam example below.



Relative Deflection	Absolute Deflection

Relative deflections are given in the member analysis results graphics and are the ones used in the member design.

Steel beam design to BS 5950

Click the links below to find out more:

- Design method (page 11)
- Steel beam limitations and assumptions (page 11)
- Ultimate limit state (strength) (page 12)
- Ultimate limit state (buckling) (page 15)
- Natural frequency checks (SLS) (page 19)
- Web openings (page 20)

Design method (Beams: BS 5950)

Unless explicitly stated all calculations are in accordance with the relevant sections of BS 5950-1:2000. You may find the handbook and commentary to the Code of Practice published by the Steel Construction Institute useful.

Steel beam limitations and assumptions (Beams: BS 5950)

The following limitations apply:

- continuous beams (more than one span) must be co-linear in the plane of the web within a small tolerance (sloping in elevation is allowed),

- rolled doubly symmetric prismatic sections (that is I- and H-sections), doubly symmetric hollow sections (i.e. SHS, RHS and CHS), and channel sections are fully designed,
- single angle, double angles and tees are designed, but certain checks are beyond scope, (see Angle and tee limitations)
- plated beams are fully designed provided the section type is either “Plated Beam” or “Plated Column”. All other plated section types (“Rolled I Sections with Plates”, “Double Rolled I Sections” etc.) are only analysed but not designed.
- Fabsec beams (with or without openings) are excluded.

The following assumptions apply:

- All supports are considered to provide torsional restraint, that is lateral restraint to both flanges. This cannot be changed. It is assumed that a beam that is continuous through the web of a supporting beam or column together with its substantial moment resisting end plate connections is able to provide such restraint.
- If, at the support, the beam oversails the supporting beam or column then the detail is assumed to be such that the bottom flange of the beam is well connected to the supporting member and, as a minimum, has torsional stiffeners provided at the support.
- In the Tekla Structural Designer model, when not at supports, coincident restraints to both flanges are assumed when one or more members frame into the web of the beam at a particular position and the cardinal point of the centre-line model of the beam lies in the web. Otherwise, only a top flange or bottom flange restraint is assumed. Should you judge the actual restraint provided by the in-coming members to be different from to what has been assumed, you have the flexibility to edit the restraints as required.
- Intermediate lateral restraints to the top or bottom flange are assumed to be capable of transferring the restraining forces back to an appropriate system of bracing or suitably rigid part of the structure.
- It is assumed that you will make a rational and “correct” choice for the effective lengths between restraints for both LTB and compression buckling. **The default value for the effective length factor of 1.0 may be neither correct nor safe.**

Ultimate limit state (strength) (Beams: BS 5950)

The checks relate to doubly symmetric prismatic sections (that is rolled I- and H-sections), to singly symmetric sections i.e. channel sections and to doubly symmetric hollow sections i.e. SHS, RHS and CHS. Other section types are not currently covered.

The strength checks relate to a particular point on the member and are carried at regular intervals along the member and at "points of interest".

Click the links below to find out more:

- Classification (page 13)
- Shear capacity (page 14)
- Moment capacity (page 14)
- Axial capacity (page 14)
- Cross-section capacity (page 15)

Classification (Beams: BS 5950)

General

The classification of the cross section is in accordance with BS 5950-1: 2000.

Steel beams can be classified as:

- Plastic Class = 1
- Compact Class = 2
- Semi-compact Class = 3
- Slender Class = 4

Class 4 sections are only acceptable for angle and tee sections.

Sections with a Class 3 web can be taken as Class 2 sections (Effective Class 2) providing the cross section is equilibrated to that described in Clause 3.5.6 where the section is given an "effective" plastic section modulus, S_{eff}. For rolled I and H sections in the UK, this gives no advantage in pure bending since the web d/t is too small. Hence for beams there is likely to be little advantage in using this approach since the axial loads are generally small, this classification is therefore not implemented.

All unacceptable classifications are either failed in check mode or rejected in design mode.

Hollow sections

The classification rules for SHS and RHS relate to "hot-finished hollow sections" only ("cold-formed hollow sections" are not included in this release).

WARNING Important Note. The classification used to determine M_b is based on the maximum axial compressive load in the relevant segment length. Furthermore, the Code clearly states that this classification should (only) be used to determine the moment capacity and lateral torsional buckling resistance to Clause 4.2

and 4.3 for use in the interaction equations. Thus, when carrying out the strength checks, the program determines the classification at the point at which strength is being checked.

Shear capacity (Beams: BS 5950)

The shear check is performed according to BS 5950-1: 2000 Clause 4.2.3. for the absolute value of shear force normal to the x-x axis (F_{vx}) and normal to the y-y axis (F_{vy}), at the point under consideration.

Shear buckling

When the web slenderness exceeds 70ε shear buckling can occur in rolled sections. There are very few standard rolled sections that breach this limit. Tekla Structural Designer will warn you if this limit is exceeded, but will not carry out any shear buckling checks.

Moment capacity (Beams: BS 5950)

The moment capacity check is performed according to BS 5950-1: 2000 Clause 4.2.5 for the moment about the x-x axis (M_x) and about the y-y axis (M_y), at the point under consideration. The moment capacity can be influenced by the magnitude of the shear force ("low shear" and "high shear" conditions). The maximum absolute shear to either side of a point load is examined to determine the correct condition for the moment capacity in that direction.

NOTE Not all cases of high shear in two directions combined with moments in two directions along with axial load are considered thoroughly by BS 5950-1: 2000. The following approach is adopted by Tekla Structural Designer:

- if high shear is present in one axis or both axes and axial load is also present, the cross-section capacity check is given a Beyond Scope status. The message associated with this status is "High shear and axial load are present, additional hand calculations are required for cross-section capacity to Annex H.3". Tekla Structural Designer does not perform any calculations for this condition.
- if high shear and moment is present in both axes and there is no axial load ("biaxial bending") the cross-section capacity check is given a Beyond Scope status and the associated message is, "High shear present normal to the y-y axis, no calculations are performed for this condition."
- if high shear is present normal to the y-y axis and there is no axial load, the y-y moment check and the cross-section capacity check are each given Beyond Scope statuses. The message associated with this condition is, "High shear present normal to the y-y axis, no calculations are performed for this condition."

Axial capacity (Beams: BS 5950)

The axial capacity check is performed according to BS 5950-1: 2000 Clause 4.6.1 using the gross area and irrespective of whether the axial force is tensile or compressive. This check is for axial compression capacity and axial tension capacity. Compression resistance is a buckling check and as such is considered under Compression Resistance.

Cross-section capacity (Beams: BS 5950)

The cross-section capacity check covers the interaction of axial load and bending to clause 4.8.2 and 4.8.3.2 appropriate to the type (for example – doubly symmetric) and classification of the section. Since the axial tension capacity is not adjusted for the area of the net section then the formula in clause 4.8.2.2 and 4.8.3.2 are the same and can be applied irrespective of whether the axial load is compressive or tensile.

The Note in Moment capacity also applies here.

Ultimate limit state (buckling) (Beams: BS 5950)

Click the links below to find out more:

- Lateral torsional buckling resistance, Clause 4.3 (page 15)
- Lateral torsional buckling resistance, Annex G (page 16)
- Compression resistance (page 17)
- Member buckling resistance, Clause 4.8.3.3.1 (page 17)
- Member buckling resistance, Clause 4.8.3.3.2 (page 18)
- Member buckling resistance, Clause 4.8.3.3.3 (page 19)

Lateral torsional buckling resistance, clause 4.3 (Beams: BS 5950)

For beams that are unrestrained over part or all of a span, a Lateral torsional buckling (LTB) check is required either:

- in its own right, clause 4.3 check,
- as part of an Annex G check,
- as part of a combined buckling check to 4.8.3.3.1, 4.8.3.3.2 or 4.8.3.3.3, (see Member buckling resistance, clause 4.8.3.3.1, Member buckling resistance, clause 4.8.3.3.2 (page 18), and Member buckling resistance, clause 4.8.3.3.3 (page 19), respectively)

This check is not carried out under the following circumstances:

- when bending exists about the minor axis only,
- when the section is a CHS or SHS,

- when the section is an RHS that satisfies the limits given in Table 15 of BS 5950-1: 2000.

For sections in which LTB cannot occur (the latter two cases above) the value of M_b for use in the combined buckling check is taken as the full moment capacity, M_{cx}, not reduced for high shear in accordance with clause 4.8.3.3.3 (c), equation 2 (See Member buckling resistance, clause 4.8.3.3.3).

Effective lengths

The value of effective length factor is entirely at your choice. The default value is 1.0 for "normal" loads and 1.2 for "destabilizing loads". Different values can apply in the major and minor axis.

Lateral torsional buckling resistance, Annex G (Beams: BS 5950)

This check is applicable to I- and H-sections with equal or unequal[1] flanges.

The definition of this check is the out-of-plane buckling resistance of a member or segment that has a laterally unrestrained compression flange and the other flange has intermediate lateral restraints at intervals. It is used normally to check the members in portal frames in which only major axis moment and axial load exist. Although not stated explicitly in BS 5950-1: 2000, it is taken that the lateral torsional buckling moment of resistance, M_b, from the Annex G check can be used in the interaction equations of clause 4.8.3.3 (combined buckling).

Since this is not explicit within BS 5950-1: 2000 a slight conservatism is introduced. In a straightforward Annex G check the axial load is combined with major axis moment. In this case both the slenderness for lateral torsional buckling and the slenderness for compression buckling are modified to allow for the improvement provided by the tension flange restraints (λ_{LT} replaced by λ_{TB} and λ replaced by λ_{TC}). When performing a combined buckling check in accordance with 4.8.3.3 the improvement is taken into account in determining the buckling resistance moment but not in determining the compression resistance. If the incoming members truly only restrain the tension flange, then you should switch off the minor axis strut restraint at these positions.

The original source research work for the codified approach in Annex G used test specimens in which the tension flange was continuously restrained. When a segment is not continuously restrained but is restrained at reasonably frequent intervals it can be clearly argued that the approach holds true. With only one or two restraints present then this is less clear. BS 5950-1: 2000 is clear that there should be "at least one intermediate lateral restraint" (See Annex G.1.1). Nevertheless, you are ultimately responsible for accepting the adequacy of this approach.

For this check Tekla Structural Designer sets m_t to 1.0 and calculates n_t. The calculated value of n_t is based on M_{max} being taken as the maximum of M_1 to M_5, and not the true maximum moment value where this occurs elsewhere in the length. The effect of this approach is likely to be small. If at any of points 1 - 5, R >1[2], then the status of the check is set to Beyond Scope.

Reference restraint axis distance, a

The **reference restraint axis distance** is measured between some reference axis on the restrained member - usually the centroid - to the axis of restraint - usually the centroid of the restraining member. The measurement is shown diagramatically in Figure G.1 of BS 5950-1: 2000.

Tekla Structural Designer does not attempt to determine this value automatically. Instead, by default, it uses half the depth of the restrained section, and you can specify a value to be added to, or subtracted from, this at each restraint point. **You are responsible for specifying the appropriate values for each restraint position. The default value of 0mm may be neither correct nor safe**.

[1] Unequal flanged sections are not currently included.

[2] Which could happen since R is based on Z and not S.

Compression resistance (Beams: BS 5950)

For most structures, all the members resisting axial compression need checking to ensure adequate resistance to buckling about both the major- and minor-axis. Since the axial force can vary throughout the member and the buckling lengths in the two planes do not necessarily coincide, both are checked. Because of the general nature of a beam, it may not always be safe to assume that the combined buckling check will always govern. Hence the compression resistance check is performed independently from the other strength and buckling checks.

Effective lengths

The value of effective length factor is entirely at your choice. The default value is 1.0 for “normal” loads and 1.2 for “destabilizing loads”. Different values can apply in the major and minor axis.

Beams are less affected by sway than columns but the effectiveness of the incoming members to restrain the beam in both position and direction is generally less than for columns. Hence, it is less likely that effective length factors greater than 1.0 will be required but equally factors less than 1.0 may not easily be justified. Nevertheless, it is your responsibility to adjust the value from 1.0 and to justify such a change.

Please note that the requirements for slenderness limits in (for example $l/r \leq 180$) are no longer included in BS 5950-1: 2000. Consequently Tekla Structural Designer does not carry out such checks. Accordingly, for lightly loaded members you should ensure that the slenderness ratio is within reasonable bounds to permit handling and erection and to provide a reasonable level of robustness.

Member buckling resistance, clause 4.8.3.3.1 (Beams: BS 5950)

This check is used for channel sections. Such sections can be Class 1, 2 or 3 Plastic, Compact or Semi-compact (Class 4 Slender sections and Effective Class 2 sections are not allowed in this release).

Note that, whilst this check could be used for any section type dealt with in the subsequent sections, the results can never be any better than the alternatives but can be worse.

Two formula are provided in clause 4.8.3.3.1, both are checked; the second is calculated twice – once for the top flange and once for the bottom flange.

See also the *Important Note* at the end of Member buckling resistance, clause 4.8.3.3.2.

Only one value of F is used, the worst anywhere in the length being checked. If the axial load is tensile, then F is taken as zero.

If this check is invoked as part of an Annex G check, and thus M_b is governed by Annex G, then m_{LT} is taken as 1.0.

Member buckling resistance, clause 4.8.3.3.2 (Beams: BS 5950)

This check is used for Class 1, 2 and 3 Plastic, Compact and Semi-compact rolled I- and H-sections with equal flanges (Class 4 Slender sections and Effective Class 2 sections are not included in this release).

Three formula are provided in clause 4.8.3.3.2 (c) to cover the combined effects of major and minor axis moment and axial force. These are used irrespective of whether all three forces / moments exist. Clause 4.9 deals with biaxial moment in the absence of axial force, clause 4.8.3.3.2 (c) can also be used in such cases by setting the axial force to zero.

All three formula in clause 4.8.3.3.2 (c) are checked; the second is calculated twice – once for each flange.

Only one value of F is used, the worst anywhere in the length being checked. If the axial load is tensile, then F is taken as zero.

WARNING Important Note. Clause 4.8.3.3.4 defines the various equivalent uniform moment factors. The last three paragraphs deal with modifications to these depending upon the method used to allow for the effects of sway. This requires that for sway sensitive frames the uniform moment factors, m_x, m_y and m_{xy}, should be applied to the non-sway moments only. In this release there is no mechanism to separate the sway and non-sway moments, Tekla Structural Designer adopts a conservative approach and sets these 'm' factors equal to 1.0 if the frame is sway sensitive (in either direction). This is doubly conservative for sway-sensitive unbraced frames since it is likely that all the loads in a design combination and not just the lateral loads will be amplified. In such a case, both the sway and non-sway moments are increased by k_{amp} and neither are reduced by the above “m” factors. The calculation of m_{LT} is unaffected by this approach, and thus if the second equation of clause 4.8.3.3.2 (c) governs, then the results are not affected.

Member buckling resistance, clause 4.8.3.3.3 (Beams: BS 5950)

This check is used for Class 1, 2 and 3 Plastic, Compact and Semi-compact hollow sections (Class 4 Slender sections and Effective Class 2 sections are not included in this release).

Four formula are provided in clause 4.8.3.3.3 (c) to cover the combined effects of major and minor axis moment and axial force. These are used irrespective of whether all three forces / moments exist. Clause 4.9 deals with biaxial moment in the absence of axial force, clause 4.8.3.3.3 (c) can also be used in such cases by setting the axial force to zero.

The second and third formula are mutually exclusive – that is the second is used for CHS, SHS and for RHS when the limits contained in Table 15 are **not** exceeded. On the other hand the third formula is used for those RHS that exceed the limits given in Table 15. Thus only three formula are checked; the first, second and fourth or the first, third and fourth. Either the second or third (as appropriate) is calculated twice – once for each “flange”.

Only one value of F is used, the worst anywhere in the length being checked. If the axial load is tensile, then F is taken as zero.

See also the *Important Note* at the end of Member buckling resistance, clause 4.8.3.3.2.

Natural frequency checks (SLS) (Beams: BS 5950)

Tekla Structural Designer calculates the approximate natural frequency of the beam based on the simplified formula published in the Design Guide on the vibration of floors (Ref. 6) which states that Natural frequency = 18 / √ δ

In line with the calculation of natural frequency of 18 / √ δ for a pin ended beam with applied UDL, we calculate δ as the maximum static instantaneous deflection based upon the composite inertia (using the short term modular ratio) but not modified for the effects of partial interaction as:

$\delta = \%max\ \delta_{self+slab} + \%max\ \delta_{other\ dead} + \%max\ \delta_{live}$

The engineer can specify:

- Percentage self wt + slab deflection (default 100%)
- Percentage other dead deflection (default 100%)
- Percentage live load deflection (default 10%)
- Factor of increased dynamic stiffness of concrete flange (default 1.1)

Web openings (Beams: BS 5950)

Circular openings as an equivalent rectangle

Each circular opening is replaced by equivalent rectangular opening, the dimensions of this equivalent rectangle for use in all subsequent calculations are:

- d_o' = 0.9 * opening diameter
- l_o = 0.45 * opening diameter

Properties of tee sections

When web openings have been added, the properties of the tee sections above and below each opening are calculated in accordance with Section 3.3.1 of SCI P355 (Ref. 10 (page 47)) and Appendix B of the joint CIRIA/SCI Publication P068 (Ref. 5 (page 47)). The bending moment resistance is calculated separately for each of the four corners of each opening.

Design

The following calculations are performed where required for web openings:

- Axial resistance of tee sections
- Classification of section at opening
- Vertical shear resistance
- Vierendeel bending resistance
- Web post horizontal shear resistance
- Web post bending resistance
- Web post buckling resistance
- Lateral torsional buckling
- Deflections

Deflections

The deflection of a beam with web openings will be greater than that of the same beam without openings. This is due to two effects,

- the reduction in the beam inertia at the positions of openings due to primary bending of the beam,
- the local deformations at the openings due to Vierendeel effects. This has two components - that due to shear deformation and that due to local bending of the upper and lower tee sections at the opening.

The primary bending deflection is established by 'discretising' the member and using a numerical integration technique based on 'Engineer's Bending Theory' - $M/I = E/R = \sigma/y$. In this way the discrete elements that incorporate all or part of an opening will contribute more to the total deflection.

The component of deflection due to the local deformations around the opening is established using a similar process to that used for cellular beams which is in turn based on the method for castellated beams given in the SCI publication, “Design of castellated beams. For use with BS 5950 and BS 449".

The method works by applying a 'unit point load' at the position where the deflection is required and using a 'virtual work technique to estimate the deflection at that position.

For each opening, the deflection due to shear deformation, δ_s, and that due to local bending, δ_{bt}, is calculated for the upper and lower tee sections at the opening. These are summed for all openings and added to the result at the desired position from the numerical integration of primary bending deflection.

Note that in the original source document on castellated sections, there are two additional components to the deflection. These are due to bending and shear deformation of the web post. For castellated beams and cellular beams where the openings are very close together these effects are important and can be significant. For normal beams the openings are likely to be placed a reasonable distance apart. Thus in many cases these two effects will not be significant. They are not calculated for such beams but in the event that the openings are placed close together a warning is given.

Composite beam design to BS 5950

Click the links below to find out more:

- Design method (page 21)
- Construction stage design (page 23)
- Composite stage design (page 25)
- Web openings (page 30)

Design method (Composite beams: BS 5950)

Unless explicitly stated all calculations are in accordance with the relevant sections of BS 5950-3.1:1990+A1:2010 (Ref. 1). You may find the handbook and commentary to the Code of Practice published by the Steel Construction Institute (Ref. 3 and 4) useful.

Construction stage design checks

When you use Tekla Structural Designer to design or check a beam for the construction stage (the beam is acting alone before composite action is achieved) the following conditions are examined in accordance with BS 5950-1:2000:

- section classification (Clause 3.5.2),

- shear capacity (Clause 4.2.3),
- moment capacity:
  - Clause 4.2.5.2 for the low shear condition,
  - Clause 4.2.5.3 for the high shear condition,
  - lateral torsional buckling resistance (Clause 4.3.6),

    NOTE This condition is only checked in those cases where the profile decking or precast concrete slab (at your request) does not provide adequate restraint to the beam.

- web openings,
- Westok checks,
  - Shear horizontal,
  - Web post buckling,
  - Vierendeel bending,
- construction stage total load deflection check.

Composite stage design checks

When you use Tekla Structural Designer to design or check a beam for the composite stage (the beam and concrete act together, with shear interaction being achieved by appropriate shear connectors) the following Ultimate Limit State and Serviceability Limit State conditions are examined in accordance with BS 5950 : Part 3 : Section 3.1 : 1990 (unless specifically noted otherwise).

Ultimate limit state checks

- section classification (Clause 4.5.2), depending on whether adequate connection is achieved between the compression flange and the slab. The section classification allows for the improvement of the classification of the section if the appropriate conditions are met,
- vertical shear capacity (BS 5950-1:2000 - Clause 4.2.3),
- longitudinal shear capacity (Clause 5.6) allowing for the profiled metal decking, transverse reinforcement and other reinforcement which has been defined,
- number of shear connectors required (Clause 5.4.7) between the point of maximum moment and the end of the beam, or from and between the positions of significant point loads,
- moment capacity:
  - Clause 4.4.2 for the low shear condition,
  - Clause 5.3.4 for the high shear condition,
- web openings.

Serviceability limit state checks

- service stresses (Clause 6.2),
- - concrete
  - steel top flange and bottom flange
- deflections (Clause 6.1.2)
  - self-weight
  - SLAB loadcase,
  - dead load,
  - imposed load[1],
  - total deflections,

  natural frequency check (Clause 6.4).

[1] This is the only limit given in BS 5950 : Part 3 : Section 3.1 : 1990.

Construction stage design (Composite beams: BS 5950)

Tekla Structural Designer performs all checks for this condition in accordance with BS 5950-1:2000 (Ref. 2)

Click the links below to find out more:

- Section classification (page 23)
- Member strength checks (page 23)
- Lateral torsional buckling checks (page 24)
- Deflection checks (page 24)

Section classification (Composite beams: BS 5950)

Cross-section classification is determined using Table 11 and clause 3.5.

The classification of the section must be Plastic (Class 1), Compact (Class 2) or Semi-compact (Class 3).

Sections which are classified as Slender (Class 4) are beyond the scope of Tekla Structural Designer.

Member strength checks (Composite beams: BS 5950)

Member strength checks are performed at the point of maximum moment, the point of maximum shear, the position of application of each point load, and at each side of a web opening as well as all other points of interest along the beam.

Shear capacity

Shear capacity is determined in accordance with clause 4.2.3. Where the applied shear force exceeds 60% of the capacity of the section, the high shear condition applies to the bending moment capacity checks (see below).

Bending moment capacity

This is calculated to clause 4.2.5.2 (low shear at point) or clause 4.2.5.3 (high shear at point) for plastic, compact and semi-compact sections.

Lateral torsional buckling checks (Composite beams: BS 5950)

BS 5950 : Part 3 : Section 3.1 : 1990 states that lateral torsional buckling checks are not required when the angle between the direction of span of the beam and that of the profile decking is greater than or equal to 45°.

When the angle is less than this, then lateral torsional buckling checks will normally be required. Tekla Structural Designerallows you to switch off these checks by specifying that the entire length between the supports is continuously restrained against lateral torsional buckling.

If you use this option you must be able to provide justification that the beam is adequately restrained against lateral torsional buckling during construction.

When the checks are required you can position restraints at any point within the length of the main beam and can set the effective length of each sub-beam (the portion of the beam between one restraint and the next) either by giving factors to apply to the physical length of the beam, or by entering the effective length that you want to use. Each sub-beam which is not defined as being continuously restrained is checked in accordance with clause 4.3.8 and Annex B of BS 5950-1:2000.

Deflection checks (Composite beams: BS 5950)

Tekla Structural Designer calculates relative deflections. (See: Deflection checks)

The following deflections are calculated for the loads specified in the construction stage load combination:

- the dead load deflections i.e. those due to the beam self weight, the Slab Wet loads and any other included dead loads,
- the imposed load deflections i.e. those due to construction live loads,
- the total load deflection i.e. the sum of the previous items.

The loads are taken as acting on the steel beam alone.

The “Service Factor” (default 1.0), specified against each loadcase in the construction combination is applied when calculating the above deflections.

If requested by the user, the total load deflection is compared with either a span-over limit or an absolute value The initial default limit is span/200.

NOTE Adjustment to deflections. If web openings have been defined, the calculated deflections are adjusted accordingly. See: Web openings (page 20)

Composite stage design (Composite beams: BS 5950)

Tekla Structural Designer performs all checks for the composite stage condition in accordance with BS 5950-3.1:1990+A1:2010 unless specifically noted otherwise.

Click the links below to find out more:

- Equivalent steel section - Ultimate limit state (ULS) (page 25)
- Section classification (ULS) (page 25)
- Member strength checks (ULS) (page 25)
- Shear connectors (ULS) (page 27)
- Section properties - serviceability limit state (SLS) (page 28)
- Stress checks (SLS) (page 29)
- Deflection checks (SLS) (page 29)
- Natural frequency checks (SLS) (page 19)

Equivalent steel section - Ultimate limit state (ULS) (Composite beams: BS 5950)

An equivalent steel section is determined for use in the composite stage calculations by removing the root radii whilst maintaining the full area of the section. This approach reduces the number of change points in the calculations while maintaining optimum section properties.

Section classification (ULS) (Composite beams: BS 5950)

For section classification purposes the true section is used. Tekla Structural Designer classifies the section in accordance with the requirements of BS 5950-1:2000 except where specifically modified by those of BS 5950-3.1:1990+A1:2010.

There are a small number of sections which fail to meet a classification of compact at the composite stage. Although BS 5950-3.1:1990+A1:2010 covers the design of such members they are not allowed in this release of Tekla Structural Designer.

Member strength checks (ULS) (Composite beams: BS 5950)

Member strength checks are performed at the point of maximum moment, the point of maximum shear, the position of application of each point load, and at each side of a web opening as well as all other points of interest along the beam.

Shear capacity (Vertical)

is determined in accordance with clause 4.2.3 of BS 5950-1:2000. Where the applied shear force exceeds 50% of the capacity of the section, the high shear condition applies to the bending moment capacity checks (see below).

Shear capacity (Longitudinal)

the longitudinal shear resistance of a unit length of the beam is calculated in accordance with clause 5.6. You can set the position and attachment of the decking and details of the reinforcement that you want to provide. Tekla Structural Designer takes these into account during the calculations.

The following assumptions are made:

- the applied longitudinal shear force is calculated at the centre-line of the beam, and at the position of the lap (if known). If the position of the lap is not known, then the default value of 0mm should be used (that is the lap is at the centre-line of the beam) as this is the worst case scenario.
- the minimum concrete depth is assumed for calculating the area of concrete when the profile decking and beam spans are parallel,
- the total concrete area is used when the profile decking and beam spans are perpendicular,
- the overall depth of the slab is used for precast concrete slabs. that is the topping is assumed to be structural and any voids or cores are ignored.

In the calculations of the longitudinal shear resistance on the beam centre-line and at the lap, the areas used for the reinforcement are shown in the following table.

Decking angle	Reinforcement type	Area used
perpendicular	transverse	that of the single bars defined or for mesh the area of the main wires[1]
	other	that of the single bars defined or for mesh the area of the main wires[1]
parallel	transverse	that of the single bars defined or for mesh the area of the main wires[1]
	other	single bars have no contribution, for mesh

Decking angle	Reinforcement type	Area used
		the area of the minor wires[2]

[1]These are the bars that are referred to as longitudinal wires in BS 4483: 1998 Table 1

[2]These are the bars that are referred to as transverse wires in BS 4483: 1998 Table 1

If the decking spans at some intermediate angle (α) between these two extremes then the program calculates:

- the longitudinal shear resistance as if the sheeting were perpendicular, v_1,
- the longitudinal shear resistance as if the sheeting were parallel, v_2,
- then the modified longitudinal shear resistance is calculated from these using the relationship, $v_1 \sin^2(\alpha) + v^2 \cos^2(\alpha)$.

Moment capacity

for the low shear condition the plastic moment capacity is determined in accordance with clause 4.4.2. For the high shear condition the approach given in clause 5.3.4 is adopted.

The overall depth of the slab is used for precast concrete slabs. That is the topping is assumed to be structural and any voids / cores are ignored.

In this calculation the steel section is ***idealized*** to one without a root radius so that the position of the plastic neutral axis of the composite section can be determined correctly as it moves from the flange into the web.

Shear connectors (ULS) (Composite beams: BS 5950)

Tekla Structural Designer checks shear connectors to clause 5.4.7. It calculates the stud reduction factor based on the number of studs in a group.

Tekla Structural Designer always uses 2 * e (and not b_r) in the calculation of k for perpendicular profiles, and always uses b_r for parallel cases.

For angled cases two values of k are calculated and summed in accordance with clause 5.4.7.4. In this instance Tekla Structural Designer uses 2 * e for the calculation of k1 and b_r for the calculation of k2.

WARNING Caution: The value of e (when used) can have a very significant effect on the value of k. This can have a dramatic effect on the number of studs required for a given beam size. Alternatively for a fixed layout of studs this can have a significant effect on the required beam size.

Optimize shear connection

Stud optimization is a useful facility since there is often some over conservatism in a design due to the discrete changes in the size of the section.

If you choose the option to optimize the shear studs, then Tekla Structural Designer will progressively reduce the number of studs either until the minimum number of studs to resist the applied moment is found, until the minimum allowable interaction ratio (for example 40% for beams with a span less than 10 m) is reached or until the minimum spacing requirements are reached. This results in partial shear connection.

The degree of shear connection is checked at the point of maximum bending moment or the position of a point load if at that position the maximum utilization ratio occurs.

NOTE During the selection process, in auto design mode point load positions are taken to be “significant” (i.e. considered as positions at which the maximum utilization could occur) if they provide more than 10% of the total shear on the beam. For the final configuration and for check mode all point load positions are checked.

To determine if the degree of shear connection is acceptable Tekla Structural Designer applies the following rules:

- If the degree of shear connection at the point of maximum moment is less than the minimum permissible shear connection, then this generates a FAIL status,
- If the point of maximum utilization ratio occurs at a point that is not the maximum moment position and the degree of shear connection is less than the minimum permissible shear connection, then this generates a WARNING status,
- If the degree of shear connection at any other point load is less than the minimum permissible shear connection, then this does not affect the status in any way.

NOTE The percentage degree of shear connection is always calculated by the program as a proportion of the maximum concrete force and not simply N_a/N_p as in the code.

Section properties - serviceability limit state (SLS) (Composite beams: BS 5950)

BS 5950-3.1:1990+A1:2010 indicates that the Serviceability Limit State modular ratio for all SLS calculations should be based upon an effective modular ratio derived from the proportions of long term loading in the design combination being considered.

Tekla Structural Designer therefore calculates the deflection for the beam based on the properties as tabulated below.

Loadcase type	Properties used
self-weight	bare beam
Slab	bare beam
Dead	composite properties calculated using the modular ratio for long term loads
Live	composite properties calculated using the effective modular ratio appropriate to the long term load percentage for each load. The deflections for all loads in the loadcase are calculated using the principle of superposition.
Wind	composite properties calculated using the modular ratio for short term loads
Total loads	these are calculated from the individual loadcase loads as detailed above again using the principle of superposition

Stress checks (SLS) (Composite beams: BS 5950)

Tekla Structural Designer calculates the worst stresses in the extreme fibres of the steel and the concrete at serviceability limit state for each load taking into account the proportion which is long term and that which is short term. These stresses are then summed algebraically. Factors of 1.00 are used on each loadcase in the design combination (you cannot amend these). The stress checks assume that full interaction exists between the steel and the concrete at serviceability state.

Deflection checks (SLS) (Composite beams: BS 5950)

Tekla Structural Designer calculates relative deflections. (See: Deflection checks)

The composite stage deflections are calculated in one of two ways depending upon the previous and expected future load history:

- the deflections due to all loads in the Slab Dry loadcase and the self-weight of the beam are calculated based on the inertia of the steel beam alone (these deflections will not be modified for the effects of partial interaction).

  NOTE It is the Slab Dry deflection alone which is compared with the limit, if any, specified for the Slab loadcase deflection. See: Web openings (page 20)

- the deflections for all loads in the other loadcases of the Design Combination will be based on the inertia of the composite section allowing for the proportions of the particular load that are long or short term (see above). When necessary these will be modified to include the effects of partial interaction in accordance with clause 6.1.4.

  NOTE It is the deflection due to imposed loads alone (allowing for long and short term effects) which is limited within the code. Tekla Structural Designer also gives you the deflection for the Slab loadcase which is useful for pre-cambering the beam. The beam Self-weight, Dead and Total deflections are also given to allow you to be sure that no component of the deflection is excessive.

  NOTE Adjustment to deflections - If web openings have been defined, the calculated deflections are adjusted accordingly.

Web openings (Composite beams: BS 5950)

Circular openings as an equivalent rectangle

Each circular opening is replaced by equivalent rectangular opening, the dimensions of this equivalent rectangle for use in all subsequent calculations are:

d_o' = 0.9 * opening diameter

l_o = 0.45 * opening diameter

Properties of tee sections

When web openings have been added, the properties of the tee sections above and below each opening are calculated in accordance with Section 3.3.1 of SCI P355 (Ref. 10) and Appendix B of the joint CIRIA/SCI Publication P068 (Ref. 5). The bending moment resistance is calculated separately for each of the four corners of each opening.

Design at construction stage

The following calculations are performed where required for web openings:

- Axial resistance of tee sections
- Classification of section at opening
- Vertical shear resistance
- Vierendeel bending resistance
- Web post horizontal shear resistance
- Web post bending resistance
- Web post buckling resistance
- Lateral torsional buckling
- Deflections

Design at composite stage

The following calculations are performed where required for web openings:

- Axial resistance of concrete flange
- Vertical shear resistance of the concrete flange
- Global bending action - axial load resistance
- Classification of section at opening
- Vertical shear resistance
- Moment transferred by local composite action
- Vierendeel bending resistance
- Web post horizontal shear resistance
- Web post bending resistance
- Web post buckling resistance
- Deflections

Deflections

The deflection of a beam with web openings will be greater than that of the same beam without openings. This is due to two effects,

- the reduction in the beam inertia at the positions of openings due to primary bending of the beam,
- the local deformations at the openings due to Vierendeel effects. This has two components - that due to shear deformation and that due to local bending of the upper and lower tee sections at the opening.

The primary bending deflection is established by 'discretising' the member and using a numerical integration technique based on 'Engineer's Bending

Theory' - M/I = E/R = σ/y. In this way the discrete elements that incorporate all or part of an opening will contribute more to the total deflection.

The component of deflection due to the local deformations around the opening is established using a similar process to that used for cellular beams which is in turn based on the method for castellated beams given in the SCI publication, “Design of castellated beams. For use with BS 5950 and BS 449".

The method works by applying a 'unit point load' at the position where the deflection is required and using a 'virtual work technique to estimate the deflection at that position.

For each opening, the deflection due to shear deformation, δ_s, and that due to local bending, δ_{bt}, is calculated for the upper and lower tee sections at the opening. These are summed for all openings and added to the result at the desired position from the numerical integration of primary bending deflection.

Note that in the original source document on castellated sections, there are two additional components to the deflection. These are due to bending and shear deformation of the web post. For castellated beams and cellular beams where the openings are very close together these effects are important and can be significant. For normal beams the openings are likely to be placed a reasonable distance apart. Thus in many cases these two effects will not be significant. They are not calculated for such beams but in the event that the openings are placed close together a warning is given.

Steel column design to BS 5950

Click the links below to find out more:

- Design method (page 32)
- Ultimate limit state (strength) (page 32)
- Ultimate limit state (buckling) (page 35)
- Serviceability limit state (page 39)

Design method (Columns: BS 5950)

Unless explicitly stated all calculations are in accordance with the relevant sections of BS 5950-1: 2000. You may find the handbook and commentary to the Code of Practice published by the Steel Construction Institute useful.

Ultimate limit state (strength) (Columns: BS 5950)

The checks relate to doubly symmetric prismatic sections i.e. rolled I- and H-sections and to doubly symmetric hot-finished hollow sections i.e. SHS, RHS and CHS. Other section types are not currently covered.

The strength checks relate to a particular point on the member and are carried out at 5th points and “points of interest”, (i.e. positions such as maximum moment, maximum axial etc.)

Click the links below to find out more:

- Classification (page 33)
- Shear capacity (page 34)
- Moment capacity (page 34)
- Axial capacity (page 35)
- Cross-section capacity (page 35)

Classification (Columns: BS 5950)

General

The classification of the cross section is in accordance with BS 5950-1: 2000.

Steel columns can be classified as:

- Plastic Class = 1
- Compact Class = 2
- Semi-compact Class = 3
- Slender Class = 4

Class 4 sections are not allowed.

Sections with a Class 3 web can be taken as Class 2 sections (Effective Class 2) providing the cross section is equilibrated to that described in Clause 3.5.6 where the section is given an “effective” plastic section modulus, S_{eff}. This approach is not adopted in the current version of Tekla Structural Designer.

All unacceptable classifications are either failed in check mode or rejected in design mode.

Hollow sections

The classification rules for SHS and RHS relate to “hot-finished hollow sections” only (“cold-formed hollow sections” are not included in this release).

WARNING important. The classification used to determine M_b is based on the maximum axial compressive load in the relevant segment length. Furthermore, the code clearly states that this classification should (only) be used to determine the moment capacity and lateral torsional buckling resistance to clause 4.2 and 4.3 for use in the interaction equations. Thus, when carrying out the strength checks, the program determines the classification at the point at which strength is being checked.

Shear capacity (Columns: BS 5950)

The shear check is performed according to BS 5950-1: 2000 clause 4.2.3. for the absolute value of shear force normal to the x-x axis and normal to the y-y axis, F_{vx} and F_{vy}, at the point under consideration.

Shear buckling

When the web slenderness exceeds 70e shear buckling can occur in rolled sections. There are very few standard rolled sections that breach this limit. Tekla Structural Designerwill warn you if this limit is exceeded, but will not carry out any shear buckling checks.

Moment capacity (Columns: BS 5950)

The moment capacity check is performed according to BS 5950-1: 2000 clause 4.2.5 for the moment about the x-x axis and about the y-y axis, M_x and M_y, at the point under consideration. The moment capacity can be influenced by the magnitude of the shear force (“low shear” and “high shear” conditions). The maximum absolute shear to either side of a point of interest is used to determine the moment capacity for that direction.

High shear condition about x-x axis

The treatment of high shear is axis dependent. In this release for CHS, if high shear is present, the moment capacity about the x-x axis is not calculated, the check is given a Beyond Scope status and an associated explanatory message.

High shear condition about y-y axis

For rolled sections in the current release, if high shear is present normal to the y-y axis then the moment capacity about the y-y axis is not calculated, the check is given a Beyond Scope status and an associated explanatory message.

For hollow sections, there is greater potential for the section to be used to resist the principal moments in its minor axis. Of course for CHS and SHS there is no major or minor axis and so preventing high shear arbitrarily on one of the two principal axes does not make sense. Nevertheless, if high shear is present normal to the y-y axis then in this release the moment capacity about the y-y axis is not calculated, the check is given a Beyond Scope status and an associated explanatory message.

Note

Not all cases of high shear in two directions combined with moments in two directions along with axial load are considered thoroughly by BS 5950-1: 2000.

The following approach is adopted by Tekla Structural Designer:

- if high shear is present in one axis or both axes and axial load is also present, the cross-section capacity check is given a Beyond Scope status. The message associated with this status is “High shear and axial load are present, additional hand calculations are required for cross-section capacity to Annex H.3”. Tekla Structural Designer does not perform any calculations for this condition.
- if high shear and moment is present in both axes and there is no axial load (“biaxial bending”) the cross-section capacity check is given a Beyond Scope status and the associated message is, “High shear present normal to the y-y axis, no calculations are performed for this condition.”
- if high shear is present normal to the y-y axis and there is no axial load, the y-y moment check and the cross-section capacity check are each given Beyond Scope statuses. The message associated with this condition is, “High shear present normal to the y-y axis, no calculations are performed for this condition.”

Axial capacity (Columns: BS 5950)

The axial capacity check is performed according to BS 5950-1: 2000 clause 4.6.1 using the gross area and irrespective of whether the axial force is tensile or compressive. This check is for axial compression capacity and axial tension capacity. Compression resistance is a buckling check and as such is considered under Compression resistance.

Cross-section capacity (Columns: BS 5950)

The cross-section capacity check covers the interaction of axial load and bending to clause 4.8.2 and 4.8.3.2 appropriate to the type (for example – doubly symmetric) and classification of the section. Since the axial tension capacity is not adjusted for the area of the net section then the formula in clause 4.8.2.2 and 4.8.3.2 are the same and can be applied irrespective of whether the axial load is compressive or tensile.

The Note in Moment capacity (page 34)also applies here.

Ultimate limit state (buckling) (Columns: BS 5950)

Click the links below to find out more:

- Lateral torsional buckling resistance, Clause 4.3 (page 36)
- Lateral torsional buckling resistance, Annex G (page 36)
- Compression resistance (page 37)
- Member buckling resistance, Clause 4.8.3.3.2 (page 38)
- Member buckling resistance, Clause 4.8.3.3.3 (page 39)

Lateral torsional buckling resistance, Clause 4.3 (Columns: BS 5950)

For columns that are unrestrained over part or all of a span, a Lateral torsional buckling (LTB) check is required either:

- in its own right, clause 4.3 check,
- as part of an Annex G check,
- as part of a combined buckling check to clause 4.8.3.3.2 or 4.8.3.3.3, (See: Member buckling resistance, Clause 4.8.3.3.2 (page 38), and Member buckling resistance, clause 4.8.3.3.3 (page 39)).

This check is not carried out under the following circumstances:

- when bending exists about the minor axis only,
- when the section is a CHS or SHS,
- when the section is an RHS that satisfies the limits given in Table 15 of BS 5950-1: 2000.

For sections in which LTB cannot occur (the latter two cases above) the value of M_b for use in the combined buckling check is taken as the full moment capacity, M_{cx}, not reduced for high shear in accordance with clause 4.8.3.3.3 (c), equation 2 (See: Member buckling resistance, Clause 4.8.3.3.2 (page 38)).

Destabilising loads are excluded from Tekla Structural Designer, this is justified by the rarity of the necessity to apply such loads to a column. If such loads do occur, then you can adjust the “normal” effective length to take this into account although you can not achieve the code requirement to set m_{LT} to 1.0.

Effective lengths

The value of effective length factor is entirely at your choice. The default value is 1.0.

Lateral torsional buckling resistance, Annex G (Columns: BS 5950)

This check is applicable to I- and H-sections with equal or unequal[1] flanges.

The definition of this check is the out-of-plane buckling resistance of a member or segment that has a laterally unrestrained compression flange and the other flange has intermediate lateral restraints at intervals. It is used normally to check the members in portal frames in which only major axis moment and axial load exist. Although not stated explicitly in BS 5950-1: 2000, it is taken that the lateral torsional buckling moment of resistance, M_b, from the Annex G check can be used in the interaction equations of clause 4.8.3.3 (combined buckling).

Since this is not explicit within BS 5950-1: 2000 a slight conservatism is introduced. In a straightforward Annex G check the axial load is combined with major axis moment. In this case both the slenderness for lateral torsional buckling and the slenderness for compression buckling are modified to allow for the improvement provided by the tension flange restraints (λ_{LT} replaced by λ_{TB} and λ replaced by λ_{TC}). When performing a combined buckling check in accordance with 4.8.3.3 the improvement is taken into account in determining the buckling resistance moment but not in determining the compression resistance. If the incoming members truly only restrain the tension flange, then you should switch off the minor axis strut restraint at these positions.

The original source research work for the codified approach in Annex G used test specimens in which the tension flange was continuously restrained. When a segment is not continuously restrained but is restrained at reasonably frequent intervals it can be clearly argued that the approach holds true. With only one or two restraints present then this is less clear.BS 5950-1: 2000 is clear that there should be “at least one intermediate lateral restraint” (See Annex G.1.1). **Nevertheless, you are ultimately responsible for accepting the adequacy of this approach.**

For this check Tekla Structural Designer sets mt to 1.0 and calculates n_t. The calculated value of n_t is based on M_{max} being taken as the maximum of M_1 to M_5, and not the true maximum moment value where this occurs elsewhere in the length. The effect of this approach is likely to be small. If at any of points 1 - 5, R >1 [2], then Tekla Structural Designer sets the status of the check to Beyond Scope.

Reference restraint axis distance, a

The *reference restraint axis distance* is measured between some reference axis on the restrained member - usually the centroid - to the axis of restraint - usually the centroid of the restraining member. The measurement is shown diagramatically in Figure G.1 of BS 5950-1: 2000.

Tekla Structural Designer does not attempt to determine this value automatically, since such an approach is fraught with difficulty and requires information from you which is only used for this check. Instead, by default, Tekla Structural Designer uses half the depth of the restrained section, and you can specify a value to be added to, or subtracted from, this at each restraint point. **You are responsible for specifying the appropriate values for each restraint position. The default value of 0mm may be neither correct nor safe.**

[1]Unequal flanged sections are not currently included.

[2] Which could happen since R is based on Z and not S.

Compression resistance (Columns: BS 5950)

For most structures, all the members resisting axial compression need checking to ensure adequate resistance to buckling about both the major- and minor-axis. Since the axial force can vary throughout the member and the buckling lengths in the two planes do not necessarily coincide, both are checked. Because of the general nature of a column, it may not always be safe to assume that the combined buckling check will always govern. Hence the compression resistance check is performed independently from all other strength and buckling checks.

Effective lengths

The value of effective length factor is entirely at your choice. The default value is 1.0. Different values can apply in the major and minor axis.

The minimum theoretical value is 0.5 and the maximum infinity for columns in rigid moment resisting (RMR) frames. Practical values for simple columns are in the range 0.7 to 2.0. Values less than 1.0 can be chosen for non-sway frames or for sway frames in which the effects of sway are taken into account using the amplified moments method. However, there is a caveat on the value of effective length factor even when allowance is made for sway.

In particular for RMR frames, the principal moments due to frame action preventing sway are in one plane of the frame. There will often be little or no moment out-of-plane and so amplification of these moments has little effect. Nevertheless the stability out-of-plane can still be compromised by the lack of restraint due to sway sensitivity in that direction. In such cases a value of greater then 1.0 (or substantially greater) may be required. Similarly, in simple construction where only eccentricity moments exist, it is only the brace forces that “attract” any amplification. Thus for the column themselves the reduced restraining effect of a sway sensitive structure may require effective length factors greater than 1.0 as given in Table 22 of BS 5950-1: 2000.

Member buckling resistance, Clause 4.8.3.3.2 (Columns: BS 5950)

This check is used for Class 1, 2 and 3 Plastic, Compact and Semi-compact rolled I- and H-sections with equal flanges (Class 4 Slender sections and Effective Class 2 sections are not included in this release).

Three formulae are provided in clause 4.8.3.3.2 (c) to cover the combined effects of major and minor axis moment and axial force.These are used irrespective of whether all three forces / moments exist. Clause 4.9 deals with biaxial moment in the absence of axial force, clause 4.8.3.3.2 (c) can also be used in such cases by setting the axial force to zero.

All three formulae in clause 4.8.3.3.2 (c) are checked; the second is calculated twice – once for Face A and once for Face C.

Only one value of F is used, the worst anywhere in the length being checked. If the axial load is tensile, then F is taken as zero.

Important Note

Clause 4.8.3.3.4 defines the various equivalent uniform moment factors. The last three paragraphs deal with modifications to these depending upon the method used to allow for the effects of sway. This requires that for sway sensitive frames the uniform moment factors, m_x, m_y and m_{xy}, should be applied to the non-sway moments only. In this release there is no mechanism to separate the sway and non-sway moments, Tekla Structural Designer adopts the only conservative approach and sets these “m” factors equal to 1.0

if the frame is sway sensitive (in either direction). This is doubly conservative for sway-sensitive unbraced frames since it is likely that all the loads in a design combination and not just the lateral loads will be amplified. In such a case, both the sway and non-sway moments are increased by kamp and neither are reduced by the above “m” factors. The calculation of m_{LT} is unaffected by this approach, and thus if the second equation of clause 4.8.3.3.2 (c) governs, then the results are not affected.

Member buckling resistance, Clause 4.8.3.3.3 (Columns: BS 5950)

This check is used for Class 1, 2 and 3 Plastic, Compact and Semi-compact hollow sections (Class 4 Slender sections and Effective Class 2 sections are not included in this release).

Four formulae are provided in clause 4.8.3.3.3 (c) to cover the combined effects of major and minor axis moment and axial force. These are used irrespective of whether all three forces / moments exist. Clause 4.9 deals with biaxial moment in the absence of axial force, clause 4.8.3.3.3 (c) can also be used in such cases by setting the axial force to zero.

The second and third formulae are mutually exclusive – that is the second is used for CHS, SHS and for RHS when the limits contained in Table 15 are **not** exceeded. On the other hand the third formula is used for those RHS that exceed the limits given in Table 15. Thus only three formulae are checked; the first, second and fourth or the first, third and fourth. Either the second or third (as appropriate) is calculated twice – once for Face C and once for Face A.

Only one value of F is used, the worst anywhere in the length being checked. If the axial load is tensile, then F is taken as zero.

See also the **Important Note** at the end of Member buckling resistance, Clause 4.8.3.3.2 (page 38).

Serviceability limit state (Columns: BS 5950)

The column is assessed for sway and the following values are reported for each stack:

- Sway X (mm) and λ_{critx}
- Sway Y (mm) and λ_{crity}
- Sway X-Y (mm)

Depending on the reported λ_{crit} the column is classified as Sway or Non sway accordingly.

NOTE A sway assessment is only performed for the column if the Lambda Crit Check box is checked on the Column Properties dialog.

If very short columns exist in the building model these can distort the overall sway classification for the building. For this reason you may apply engineering judgement to uncheck the Lambda Crit Check box for those columns for which a sway assessment would be inappropriate

Steel brace design to BS 5950

Design method

Unless explicitly stated all brace calculations are in accordance with the relevant sections of BS 5950-1:2000 (Ref. 2).

A basic knowledge of the design methods for braces in accordance with the design code is assumed.

Classification

No classification is required for braces in tension.

Braces in compression are classified according to Clause 3.5 as either: Class 1, Class 2, Class 3 or Class 4.

Class 4 sections are not allowed.

Hollow sections

The classification rules for SHS and RHS relate to “hot-finished hollow sections” only (“cold-formed hollow sections” are not included in this release).

Axial Tension

An axial tension capacity check is performed according to clause 4.6.

Axial compression

An axial compression capacity check is performed according clause 4.7.

Compression buckling

If axial compression exists, the member is also assessed according to clause 4.7 with all relevant sub-clauses.

The default effective length in each axis is 1.0L.

Steel single, double angle and tee section design to BS 5950

Click the links below to find out more:

Design method (Angles and tees: BS 5950)

The design method adopted is dictated by the member characteristic type:

- “Beam”, “Truss member top” or “Truss member bottom” characteristic:
    - Member is designed for axial tension, compression, shear, bending and combined forces - consistent with the method detailed in Steel beam design to BS 5950 (page 11)
- “Brace”, “Truss internal” or “Truss member side” characteristic:
    - Member is designed for axial tension, compression and compression buckling only - consistent with the method detailed in Steel brace design to BS 5950

NOTE Additional Angle and tee limitations (page 41) have to be considered when designing these sections to the above design methods.

Angle and tee limitations (BS 5950)

In the current version when designing tees, single, and double angles to BS 5950, the following checks remain beyond scope:

	Tee	Angle	Double Angle
Classification	ok	ok	ok
Axial tension	ok	ok	ok
Axial compression	ok	ok	ok
Shear	ok	ok	ok
Bending	ok	ok	ok
Combined strength	ok	ok	ok
LTB	ok	ok	Beyond scope

	Tee	Angle	Double Angle
Combined buckling	ok	ok	Beyond scope
Deflection	ok	ok	ok

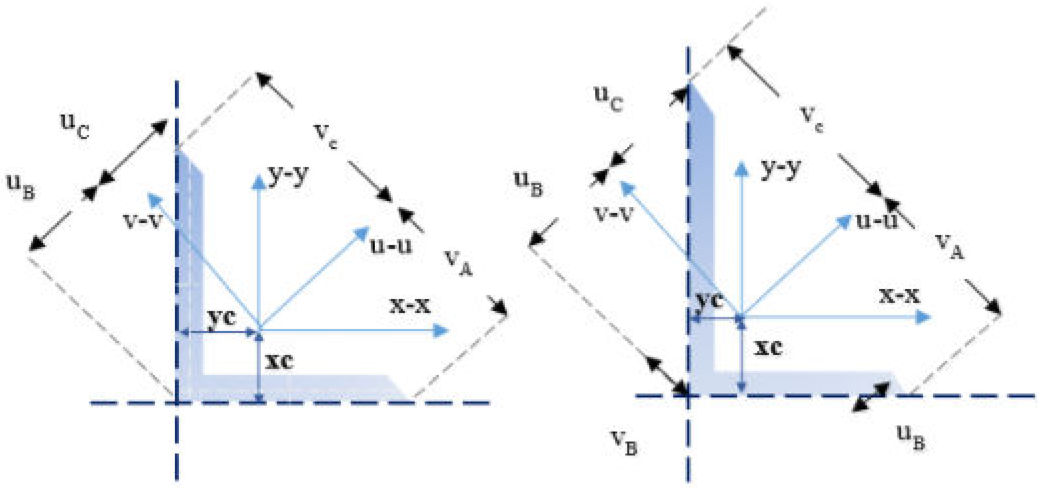
In addition, the following limitations apply:

- All sections are assumed to be effectively loaded through the shear centre such that no additional torsion moments are developed. In addition no direct allowance is made for 'destabilizing loads'.
- Design excludes bending of the outstand leg of double angles loaded eccentrically e.g. supporting masonry.
- Conditions of restraint can be defined as top and bottom flange for lateral torsional buckling. It is upon these that the buckling checks are based. For the current release intermediate LTB restraints are omitted (i.e. only fully restrained for LTB, or unrestrained).
- Double angles and tee sections subject to moment with high shear are beyond scope.

Section axes (Angles and tees: BS 5950)

For all sections:

- x-x is the axis parallel to the flanges (major axis)
- y-y is the axis perpendicular to the flanges (minor axis)
- for Single angles and Double angles
  - y-y parallel to long side (leg) - single angles
  - y-y parallel to long side (leg) - double angles with long leg back to back
  - y-y parallel to short side (leg) - double angles with short leg back to back
- u-u is the major principal axis for single angles
- v-v is the minor principal axis for single angles



Single angles - Section axes

Design procedures (Angles and tees: BS 5950)

This section includes key notes and assumptions made for the British Standard design of tees and angle sections.

Classification checks

For axial compression and bending both the web and flange (Leg 1 and Leg 2) are classified as Class 1, Class 2, Class 3 or Class 4 and the worst of the two is the resultant classification for that cross section.

The rules from Table 11 and 12 of BS 5950-1:2000 apply for the classification of these sections.

NOTE Class 4 section classification is only allowed for tees, double angles and single angles.

Axial tension check

Section 4.6 of BS 5950 is used for this design check.

Axial compression check

Section 4.6 of BS 5950 is used for this design check.

Shear check

Section 4.2.3 of BS 5950 is used for this design check.

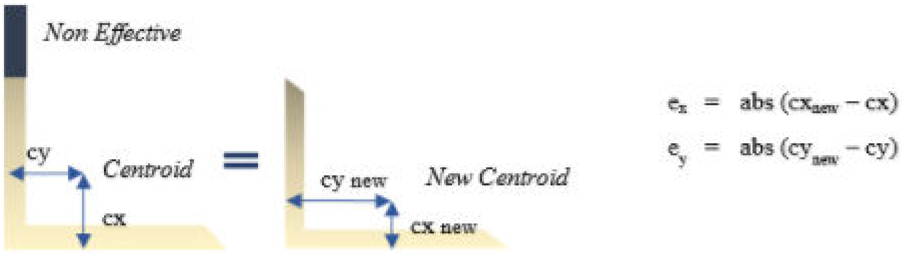
Moment check

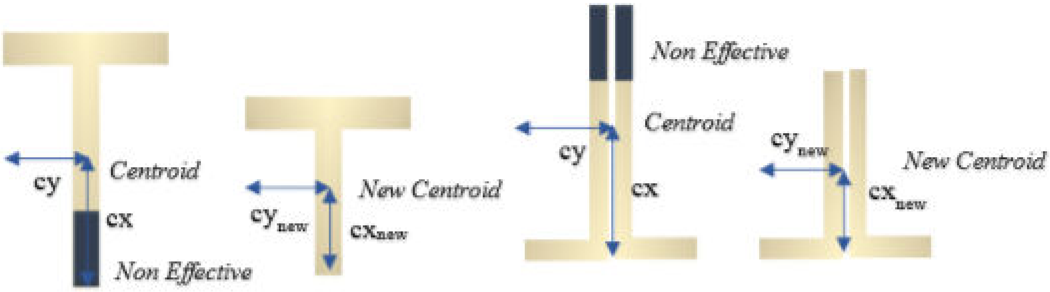
Section 4.2.5 of BS 5950 is used for this design check.

NOTE Tees, single angles and double angles are designed as Class 4.

Moment capacity for Class 4 slender sections:

Class 4 sections are designed as Class 3 effective sections.





Hence, additional moments are induced in the member due to the shift of the centroid of the effective cross-section compared to that of the gross section when under axial compression only.

Thus:

$\Delta M_{Ed,x} = e_x \times F_c$

$\Delta M_{Ed,y} = e_y \times F_c$

Where:

F_c is the max compressive force in the span.

For tees and double angles $e_x = 0$. Hence, total minor design moment = minor design moment.

Where:

e_x and e_y = the shift of the centroid of the effective area A_{eff} relative to the centre of gravity of the gross cross section

$e_x = \text{abs}(cx_{new} - c_x)$

$e_y = \text{abs}(cy_{new} - c_y)$

So finally, a total moment is obtained for which the moment design check is performed:

$M_{total\ x} = Abs(M_{Ed,x}) + Abs(\Delta M_{Ed,x})$

$M_{total\ y} = Abs(M_{Ed,y}) + Abs(\Delta M_{Ed,y})$

Single angles - asymmetric sections:

Single angles **with continuous lateral – torsional restraint** along the length are permitted to be designed on the basis of **geometric axis (x, y) bending**.

Single angles **without continuous lateral – torsional restraint** along the length are designed using the provision for **principal axis (u, v) bending** since we know that the principal axes do not coincide with the geometric ones.

$\Delta M_u = \Delta M_x \times \cos\vartheta + \Delta M_y \times \sin\vartheta$

$\Delta M_v = -\Delta M_x \times \sin\vartheta + \Delta M_y \times \cos\vartheta$

Note that when principal axis design is required for single angles and the classification is Class 4, all moments are resolved into the principal axes (total moment in the principal axes u-u and v-v).

NOTE Tees, single angles and double angles subject to moment with high shear are beyond scope.

Combined bending and axial check

Section 4.8.3 of BS 5950 is used for this design check.

For Class 3:

$Abs\ (F_c / A_g P_y) + abs\ (M_{x,Ed} / M_{cx}) + abs\ (M_{y,Ed}/W_{el,min,y}) \leq 1.0$

For Class 4:

$Abs\ (F_c/A_{eff} p_y) + (abs\ (M_{x,Ed}) + abs\ (\Delta M_{x,Ed})) / M_{cx} + abs\ (M_{y,Ed}) + abs\ (\Delta M_{y,Ed})) / M_{cy} \leq 1.0$

Note that total moments are used when the section classification is Class 4.

Lateral torsional buckling check

Section 4.3 of BS 5950 is used for this design check.

NOTE This check is beyond scope for double angles.

In the case of a beam with continuous lateral torsional restraint along its length this check is not performed. The lateral torsional resistance is considered adequate.

For beams that are unrestrained, a Lateral torsional buckling (LTB) check is required, either:

- In its own right check for LTB, clause 4.3, and B2.8 for tee sections and B.2.9 for angle sections in BS 5050-1: 2000.
- As part of combined buckling, clause 4.8 “Members with combined moment and axial force”, 4.8.3.3, for single Angles I3 and I4 sections

This check is not performed when bending exists about the minor axis only

NOTE Conditions of restraint can be defined as top and bottom flange for lateral torsional buckling. It is upon these that the buckling checks are based. All intermediate LTB restraints for tees and single angles are ignored.

Combined buckling check

NOTE This check is beyond scope for double angles.

Single angles:

Clause I.4 - For beam with continuous lateral torsional restraint or for equal single angle sections with b/t ≤ 15ε a combined buckling check is performed according to clause I.4.3 - the simplified method.

For any other case clause 4.8.3.3.1 is used with the moments being resolved into the principal axes u-u and v-v. Two formula are provided in clause 4.8.3.3.1, both are checked

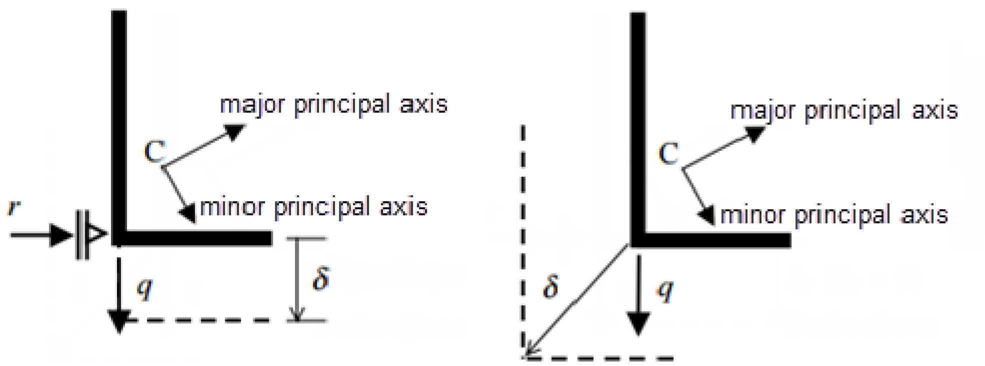
Tees:

Clause 4.8.3.3.1 is used. Two formula are provided in clause 4.8.3.3.1, both are checked.

- If the axial load is tensile, then F is taken as zero
- Only one value of F is used, the worst anywhere in the length being checked
- Class 4 slender sections are allowed

Deflection of single angles

If a single angle is continuously restrained the major geometric moment and major geometric section properties are used in the general equation governing the beam deflection.



Single angle deflections (continuously restrained, unrestrained)

However, because single angle geometric axes are not coincident with the principal axes; a different procedure is required if the angle is not continuously restrained, the procedure being as follows:

1. External loads are transposed from the geometric axes to the principal axes.
2. The deflection equations are used to calculate deflections in the principal axes.
3. These principal axis deflections are then transposed to geometric axes again.

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