The "General Method" of EN 1993-1-1

Clause 6.3.4 of EN 1993-1-1 describes a "General Method" for lateral and lateral torsional buckling of structural components, ideally suited to software applications. Although the UK National Annex places some limitations on the use of this method, it is possible that the approach will become more widely used. In the first of two articles, Dr.József Szalai, of ConSteel Solutions Ltd describes the background to the method.

Element design

When verifying the stability of beam-columns (members under combined axial load and bending) there are three different procedures in the current version of EN 1993-1-1:

1. An imperfection approach described in Sections 5.2 and 5.3
2. An isolated member approach described in Sections 6.3.1, 6.3.2 and 6.3.3
3. The so-called general method described in Section 6.3.4

In the first approach the structural model is subjected to appropriate geometrical imperfections and after a completing a second order analysis only the cross section resistances need be checked (clause 5.2.2(7)(a)). This method is generally not used in practice due to the uncertainty in the definition of the shapes, amplitudes and signs of the equivalent imperfections. The second approach is the conventional engineering solution for buckling problems, but is limited to uniform members only with relatively simple support and loading conditions. The method is based on two essential simplifications:

- Structural member isolation: the relevant member is isolated from the global structural model by applying special boundary conditions (supports, restraints or loads) at the connection points which are taken into account in the calculation of the buckling resistance.
- Buckling mode separation: the buckling of the member is calculated separately for the pure modes: flexural buckling for pure compression and lateral-torsional buckling for pure bending, and the two effects are connected by applying special interaction factors.

Although EN 1993-1-1 provides direction on the calculation of interaction factors in Annex A and Annex B, the choice of appropriate buckling lengths for complex problems is left entirely to the engineer.

The general method is a new approach for stability design and only appeared late in the development of the Eurocodes – the general method did not appear in the draft of 1992, for example. The basic idea behind the general method is that it no longer isolates members and separates the pure buckling modes, but considers the complex system of forces in the member and evaluates the appropriate compound buckling modes. The method offers the possibility to provide solutions where the isolated member approach is not entirely appropriate:

1. The general method is applicable not only for single, isolated members but also for sub frames or complete structural models where the governing buckling mode involves the complete frame;
2. The general method can examine irregular structural members such as tapered members, haunched members, and built-up members;
3. The general method is applicable for any irregular load and support system where separation into the pure buckling modes is not possible.

Although in the current version of the Eurocode the general method is recommended only for lateral and lateral-torsional buckling of structural components, the basic approach may be extended to other cases. A number of research projects are underway across Europe intended to verify and widen its applicability.

Description of the general method

The rules of the general method can be found in EN 1993-1-1 Section 6.3.4. Because the expressions and nomenclature within this Section of the Standard are likely to be unfamiliar, a column buckling problem is firstly used as a simple example. The steps to verify the stability design of a compressed member according to the conventional isolated member approach are as follows:

- ***Step 1***
  Calculate the design value of the compressive force on the member
- ***Step 2***
  Calculate the compression resistance of the cross section of the member
- ***Step 3***
  Calculate the elastic critical compressive force of the member (N_{cr})
- ***Step 4***
  Calculate the member slenderness, $\bar{\lambda}$ and the reduction factor, χ
- ***Step 5***
  Calculate the design buckling resistance of the member.

	Isolated member approach	General method
Step 1	N_{Ed}	N_{Ed}
Step 2	$N_{c,Rk}$ – Eqs. 6.10 - 6.11	$\alpha_{ult,k} = \dfrac{N_{c,Rk}}{N_{Ed}}$ – Section 6.3.4(2)
Step 3	N_{cr} – Section 6.3.1.2(1)	$\alpha_{cr,op} = \dfrac{N_{cr}}{N_{Ed}}$ – Section 6.3.4(3)
Step 4	$\bar{\lambda} = \sqrt{\dfrac{N_{c,Rk}}{N_{cr}}}$ – Eq 6.49 $\chi = \dfrac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}}$ – Eq 6.49	$\bar{\lambda}_{op} = \sqrt{\dfrac{\alpha_{ult,k}}{\alpha_{cr,op}}} = \sqrt{\dfrac{N_{c,Rk}}{N_{cr}}}$ – Eq. 6.64 Calculate χ_{op}
Step 5	$\dfrac{N_{Ed}}{N_{b,Rd}} = \dfrac{N_{Ed}}{\chi N_{c,Rd}} \le 1.0$ – Eq 6.46	$\dfrac{\chi_{op}\alpha_{ult,k}}{\gamma_{M1}} = \dfrac{\chi_{op}N_{c,Rd}}{N_{Ed}} \ge 1.0$ – Eq 6.63

Table 1

Table 2

	Isolated member approach	General method
Step 1	$N_{Ed,} M_{y,Ed}$	$N_{Ed,} M_{y,Ed}$
Step 2	$N_{c,Rk}$ – Eqs. 6.10 - 6.11 $M_{c,Rk}$ – Eqs. 6.13 - 6.15	$\alpha_{ult,k} = \min\left(\alpha_{ult,k,N} = \frac{N_{c,Rk}}{N_{Ed}} ;\ \alpha_{ult,k,N} = \frac{M_{c,Rk}}{M_{Ed}} \right)$ – Section 6.3.4(2)
Step 3	N_{cr} – Section 6.3.1.2(1) M_{cr} – Section 6.3.2.2(2)	$\alpha_{cr,op} = \min\left(\alpha_{cr,N} = \frac{N_{cr}}{N_{Ed}} ;\ \alpha_{ult,k,N} = \frac{M_{cr}}{M_{y,Ed}} \right)$ – Section 6.3.4(3)
Step 4	$\bar{\lambda}_z = \sqrt{\frac{N_{c,Rk}}{N_{cr}}}$ and hence χ – Eq 6.49 $\bar{\lambda}_{LT} = \sqrt{\frac{M_{c,Rk}}{M_{cr}}}$ and hence χ_{LT} – Eq 6.56	$\bar{\lambda}_{op} = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{cr,op}}}$ and hence χ_{op} – Eq. 6.64
Step 5	k_{zy} – Annex A, Annex B	—
Step 6	$\frac{N_{Ed}}{N_{b,Rd}} + k_{zy} \frac{M_{y,Ed}}{M_{b,Rd}} \leq 1.0$ – Eq 6.62	$\frac{\chi_{op}\alpha_{ult,k}}{\gamma_{M1}} \geq 1.0$ – Eq 6.63

In Table 1 the above steps are summarized using the expressions and nomenclature of the conventional isolated member approach. The second column indicates the equivalent approach according to the general method.

In this example the general method is seen as a simple rephrasing of the expressions in which the key steps of the generalization are ***Step 2*** and ***Step 3*** where the forces are replaced by suitable load amplifiers. In order to see clearly the real meaning and significance of this generalization the following example examines the steps of the stability design of a member subjected to compression and bending where the relevant buckling mode is the interaction of minor axis flexural and lateral-torsional buckling:

- ***Step 1***
  Calculate the design values of the compressive force and bending moment on the member
- ***Step 2***
  Calculate the compression and bending resistances of the cross section
- ***Step 3***
  Calculate the pure elastic critical compressive force according to minor axis flexural buckling (N_{cr}) and the pure elastic critical bending moment of the member (M_{cr})
- ***Step 4***
  Calculate the member slenderness and reduction factors separately for pure minor axis flexural buckling and pure lateral-torsional buckling ($\bar{\lambda}$, χ, $\bar{\lambda}_{LT}$ and χ_{LT}
- ***Step 5***
  Calculate the interaction factors connecting the two pure buckling cases (Annex A or Annex B)
- ***Step 6***
  Calculate the design buckling resistance of the member and check the member combination of axial load and bending according to expressions 6.61 and 6.62

In Table 2 the above steps are summarized using the expressions and nomenclature of the conventional isolated member approach. The second column indicates the equivalent approach according to the general method.

In Figure 1 the meaning of the load amplifiers of ***Step 2*** and ***Step 3*** is illustrated. It is important to note that one cross section resistance, one elastic critical load factor and accordingly one slenderness and one reduction factor are determined. This makes the evaluation procedure simple, even though complex loading and buckling behaviour have been assessed. The accurate calculation of the factors used in the general method usually requires more refined analysis methods or specific software tools. In the next article the practical application of the general method will be covered, demonstrating that the general method offers opportunities for an efficient design procedure.

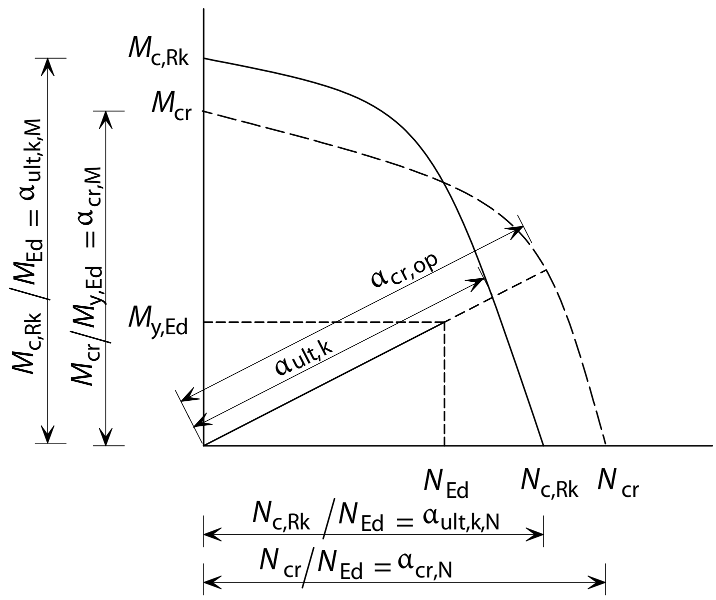

Figure 1: Load amplifiers for the conventional and the general methods