Use of LTBeamN

Calculating N_{cr} and M_{cr} by hand for use in Eurocode design can be challenging for anything but the simple cases. LTBeamN, a free software tool, can readily calculate these values, including complex situations such as tapered beams and unusual restraint arrangements. Constantinos Kyprianou, Engineer at the Steel Construction Institute, offers an overview on the use of LTBeamN and compares its results with some standard cases.

Introduction

LTBeamN was developed by CTICM and is a considerable upgrade to its predecessor LTBeam. The latest version has improved interfaces, improved graphics and the capability to analyse complex scenarios, including tapered members. The 'N' indicates that the scope of the latest version includes the effect of axial compression.

Buckling resistance

Under pure compression, BS EN 1993-1-1 requires the elastic critical force N_{cr} to be calculated. Although this is straightforward for flexural buckling, it is not straightforward for torsional or torsional-flexural buckling, especially if the section is not bi-symmetric, or has intermediate restraints to one flange. In these situations, LTBeamN can provide a convenient solution.

For unrestrained beams, the Eurocode requires that the elastic critical moment M_{cr} is determined. Although closed expressions may be used to calculate M_{cr} for orthodox cases, the calculation becomes effectively impossible without software for more complex scenarios.

Using LTBeamN

The aim of this article is to describe some of the most important features of LTBeamN and to demonstrate the verification of some standard cases.

Users can define almost any common open section, either by choosing it from a pre-defined catalogue, or by defining dimensions for a common forms of cross sections, or by section properties for unorthodox sections. The program restricts sections to mono-symmetric.

Member definition

Users can vary the depth of the section along its length, in order to allow the analysis of haunched and tapered sections, and assemble members from different upper and lower sections. Figure 1, below, shows a member with a haunched section at one end and a tapered section at the other, demonstrating the versatility of the software.

Restraints

LTBeamN allows flexibility when defining restraints, in terms of position in both dimensions. Restraints can be defined at any position in the web, at the flange or above the flange. Users can define the behaviour for each restraint with four different degrees of freedom. To create a lateral restraint, the lateral displacement is set to "fixed". For torsional restraints, the degree of freedom "θ" (which is twisting) is additionally set to "fixed". Some effort needs to be invested in appreciating the opportunities for unorthodox restraint conditions, such as spring supports.

Applied actions

LTBeamN has a number of different ways to define applied actions. Firstly, "External Loading" may be used to define point loads and distributed loads along the length and the depth of the member. Self weight may be included as an option. Alternatively, the "Internal Loading" option may be used to define the bending moment diagram and axial load directly.

Special features

LTBeamN has the facility to calculate solutions for up to 10 buckling modes, as illustrated in Figure 2, which is educational, even if not directly used in design, since in design the first buckling mode with the lowest value of N_{cr} and M_{cr} is of most interest.

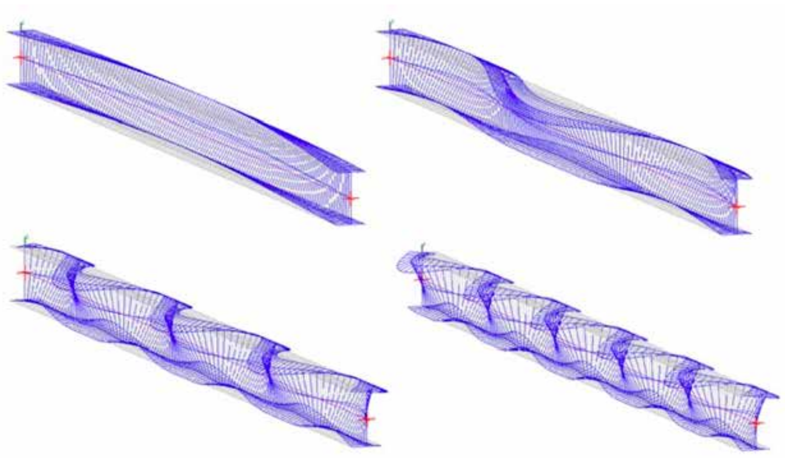

Figure 2: Various buckling modes

Analysis results

LTBeamN provides numerical results and a graphical output. The

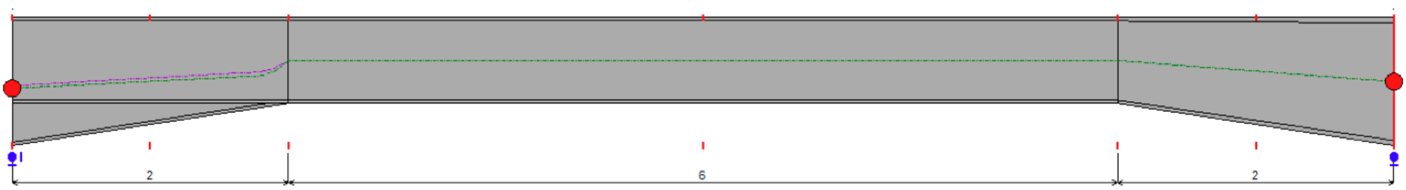

Figure 1: Member with a haunched and tapered section

visual representation of the buckled form can be particularly useful when checking that the buckled form recognises the restraint conditions anticipated by the user. As with all software, it is beneficial to have an expectation of the results and buckled form before using the program.

The results may be filtered by 'blocking' to provide the values for M_{cr} or N_{cr} in isolation. For M_{cr} alone, the option "N Blocked" is selected, and vice versa if N_{cr} is required. The combined effect of M_{cr} and N_{cr} can be calculated if required.

Verification

In this article, the use of LTbeamN is compared to a series of standard situations, using a 610 × 305 × 179 universal beam.

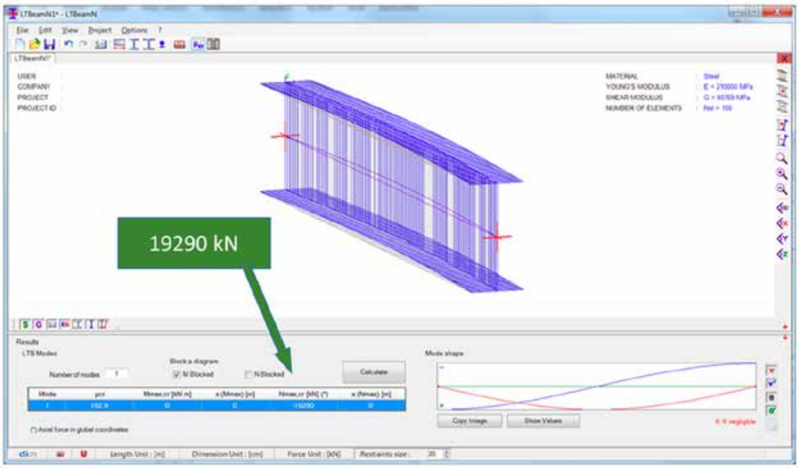

Figure 3: $N_{cr,E}$ from LTBeamN

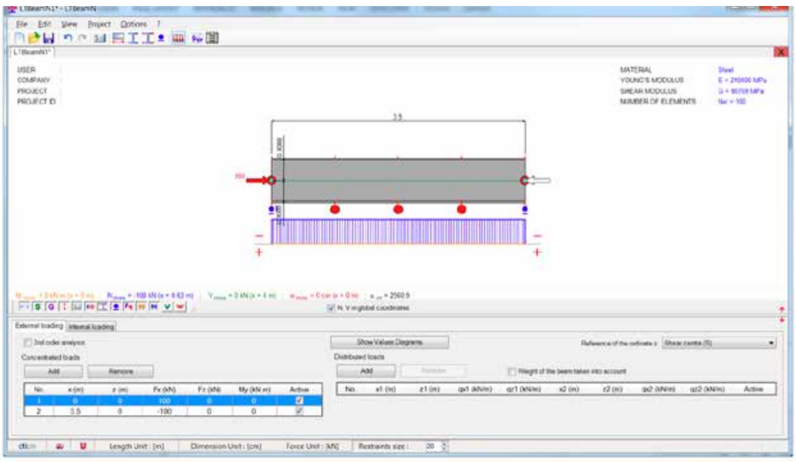

Figure 4: $N_{cr,T}$ from LTBeamN - intermediate restraints to one flange

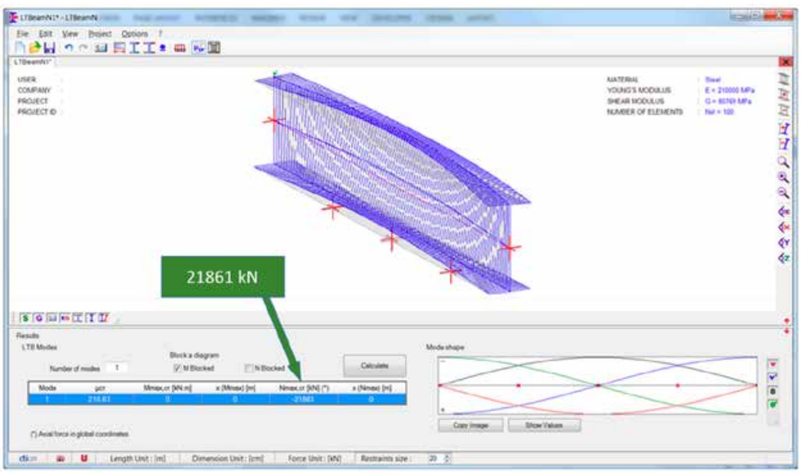

Figure 5: $N_{cr,T}$ from LTBeamN – buckled form

Elastic critical force for flexural buckling

The elastic critical flexural buckling force can be calculated using Euler's equation:

$$N_{cr,E} = \frac{\pi^2 EI_z}{L^2} = \frac{\pi^2 \times 210000 \times 11400 \times 10^4}{3500^2} \times 10^{-3} = 19288 \text{ kN}$$

Using LTBeamN, a compressive forces is applied at either end of the section. Torsional restraints are modelled at each end of the section, at the shear centre. As shown by Figure 3, N_{cr} from LTBeamN was calculated as -19290 kN. The difference is not significant and is due to the slight difference between the section properties given in the software library and in the "Blue Book". The negative sign simply reflects the convention used in modelling.

Elastic critical force for torsional buckling

The equation presented in BS EN 1993-1-1 Annex BB.3.3.1 evaluates the elastic critical torsional buckling force of an I-section between torsional restraints with intermediate lateral restraints to the tension flange:

$$N_{cr,T} = \frac{1}{i_s^2}\left(\frac{\pi^2 E I_z a^2}{L_t^2} + \frac{\pi^2 E I_w}{L_t^2} + GI_t\right)$$

where:

$$i_s^2 = i_y^2 + i_z^2 + a^2$$

a is the distance between the centroid of the member and the centroid of a restraining member, such as purlins. In this example, the restraining member is taken as 180 mm deep.

Therefore:

$$a = 180/2 + h/2 = 90 + 620.2/2 = 400.1 \text{ mm}$$

$$i_s^2 = 259^2 + 70.7^2 + 400.1^2 = 232159.5 \text{ mm}^2$$

$$N_{cr,T} = \frac{1}{232159.5}\left(3.09{\times}10^{12} + 1.726{\times}10^{12} + 2.746{\times}10^{11}\right) \times 10^{-3} = 21927 \text{ kN}$$

In LTBeamN, three intermediate lateral restraints at equal distances along the length acting 400.1mm vertically from the shear centre were introduced, as shown in Figure 4. The calculated elastic critical force is 21861 kN. The buckled form is shown in Figure 5.

If a continuous restraint is modelled at 400.1 mm below the shear centre (as an alternative to three discreet restraints), N_{cr} = 21861 kN, as previous. This demonstrates that in this case, the effect of the intermediate restraints is equivalent to a continuous restraint.

Elastic critical moment, M_{cr}

For an unrestrained beam with a uniform bending moment diagram, $C_1 = 1$ and M_{cr} is given by:

$$M_{cr} = C_1 \frac{\pi^2 EI_z}{L^2}\sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{\pi^2 EI_z}}$$

$$= 1 \times 19.3 \times 10^6 \times \sqrt{89.4{\times}103 + 14.2{\times}10^3} \times 10^{-6}$$

$$= 6212 \text{ kNm}$$

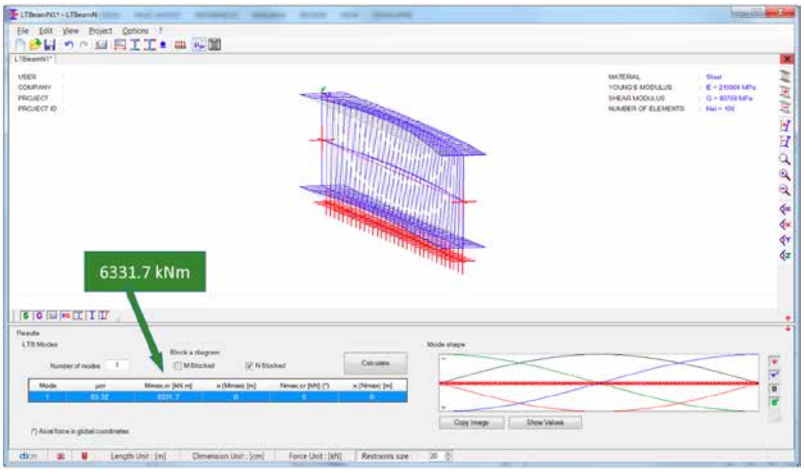

Figure 6: Continuous restraint outside the tension flange

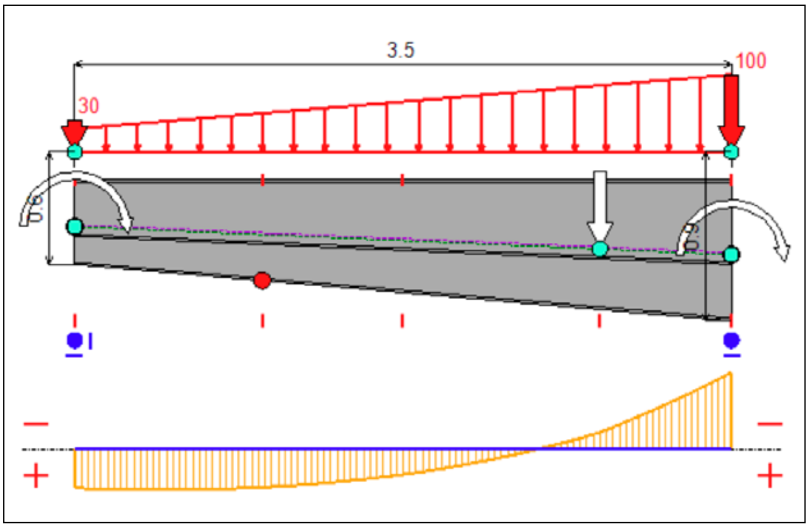

Figure 7: Unorthodox member, restraints and loading

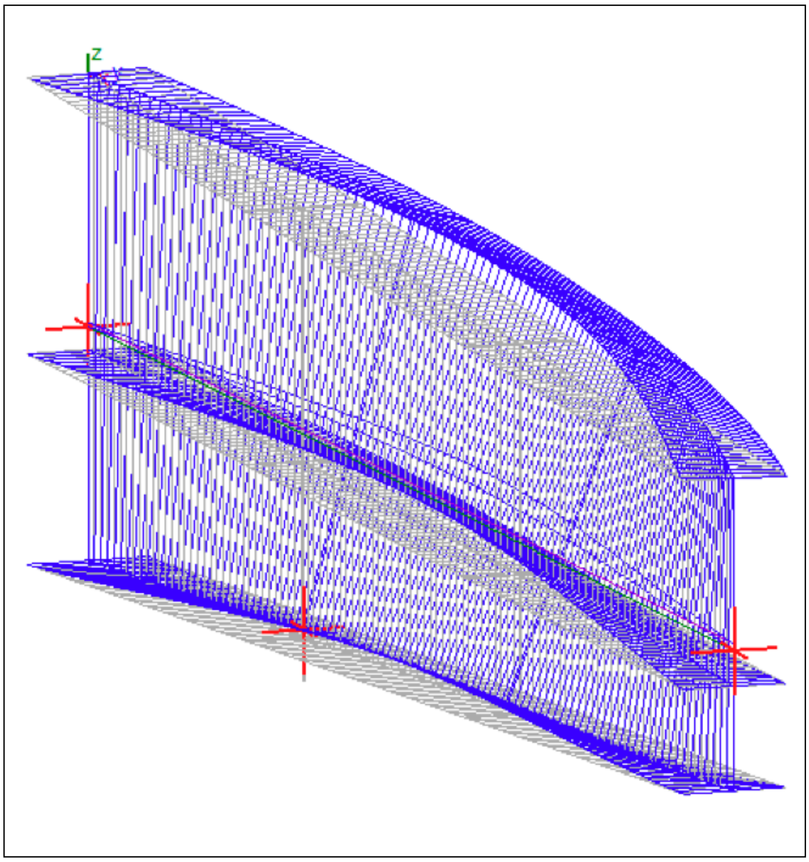

Figure 8: Buckled form of an unorthodox member

With a uniform moment, modelled with an equal moment at each end of the member, LTBeamN calculates M_{cr} as 6176 kNm. The difference in values is insignificant.

Tension flange restraint

For simple cases of tension flange restraint, closed expressions are available. Assuming continuous lateral restraint along the tension flange, $M_{cr,T}$ for a uniform bending moment diagram is given by:

$$M_{cr,T} = \frac{i_s^2}{2\alpha} N_{cr,T} = \frac{232159.5}{2 \times 400.1} \times 21927 \times 10^{-3} = 6362 \text{ kNm}$$

A continuous restraint may be modelled in LTBeamN. In this case the restraint is at 400.1 mm from the shear centre. The results from LTBeamN are shown in Figure 6.

The calculated value of M_{cr} is 6331.7 kNm; the difference is small enough to be ignored and probably follows from the use of rounded values in the closed expression and the slightly different section properties used in the software library.

Complex situations

Although the verifications presented here are all for common cases, where closed solutions are available, software is almost essential in unorthodox cases. Figure 7 shows:

- A haunched section, tapering in elevation and width
- An intermediate restraint to one flange only
- Point loads, varying distributed loads and bending moments applied (the distributed load is applied as a destabilising load, above the flange)

In this (admittedly obscure) situation, software is the only feasible approach. M_{cr} can be calculated and the buckled form examined (Figure 8).

Conclusion

LTBeamN facilitates the efficient calculation of N_{cr} and M_{cr}, being particularly useful in complex situations not covered by standard expressions. Some effort must be expended in becoming familiar with the tool and understanding all the options available. Before using the software, some expectation of the result is important, not to verify the inner workings of the software, but to ensure the data has been input correctly.