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Lateral Torsional Buckling of an Eccentrically Loaded Channel Section Beam

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***Abstract*—**Channel sections are widely used in practice as beams. However, design rules for eccentrically loaded (not through shear center) beams with channel cross- sections are not available in Eurocode 3. This paper compares the ultimate loads based on the adjusted design rules for lateral torsional buckling of eccentrically loaded channel beams in bending to the ultimate loads obtained with Finite Element (FE) simulations on the basis of a parameter study. Based on the proposed design rule, this study has led to a new design rule which conforms to Eurocode 3.

***Keywords*—**ANSYS, Eurocode 3, finite element method, lateral torsional buckling, steel channel beam.

I. Introduction

STEEL channel sections are often used in the building practice. The structural behavior of mono-symmetric channel sections is different from that of double- symmetric cross sections such as solid or I shaped cross section as shown in Fig. 1. This difference exists because the shear center (S) and center of gravity (C) do not coincide. If the applied load goes through the shear center of a channel section (Fig. 1 (c)), the load is called “centric”. It has been shown that [1]-[4] standard code requirements for lateral torsional buckling of double symmetric cross-sections can be used for the design of centrically loaded channel sections.

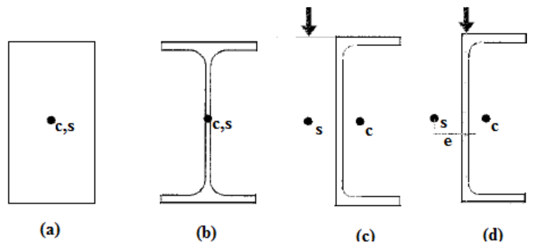

Fig. 1 Cross section: (a) solid, (b) double symmetric, (c) centrically loaded, (d) eccentrically loaded

II. Theoretical Background

In a practice channel sections are most frequently eccentrically loaded. However, no specific design rules are available in Eurocode 3 [5], [6] for lateral torsional buckling of eccentrically loaded channel sections used as beam. On the basis of parameter study, a new design rule is proposed in literature [7], [8], which is in line with the design rule in Eurocode 3.

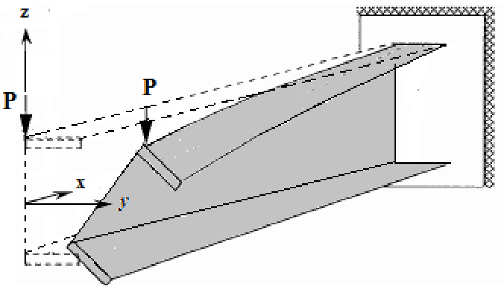

Fig. 2 Channel beam loaded through the web

A. Modified χ_{LT} Method

For channel sections, the relative slenderness $\bar{\lambda}_{LT}$ must first be adjusted to account for torsion. This has been achieved by adding a term $\bar{\lambda}_T$. The modified relative slenderness $\bar{\lambda}_{MT}$ to account for the eccentrically loaded channel sections is as:

$$\bar{\lambda}_{MT} = \bar{\lambda}_{LT} + \bar{\lambda}_T \tag{1}$$

The torsion term $\bar{\lambda}_T$ depends on the relative slenderness as:

$$\begin{aligned} \bar{\lambda}_T &= 1.1 - \bar{\lambda}_{LT} && \text{if} \quad 0.5 \le \bar{\lambda}_{LT} \prec 0.75 \\ \bar{\lambda}_T &= 0.69 - 0.44\bar{\lambda}_{LT} && \text{if} \quad 0.75 \le \bar{\lambda}_{LT} \prec 1.14 \\ \bar{\lambda}_T &= 0.19 && \text{if} \quad \bar{\lambda}_{LT} \ge 1.14 \end{aligned} \tag{2}$$

The adjusted reduction factor is given by:

$$\chi_{LT} = \frac{1}{\varphi_{LT} + \left[\varphi_{LT}^2 - \bar{\lambda}_{MT}^2\right]^{0,5}} \tag{3}$$

with:

$$\varphi_{LT} = 0,5\left[1 + \alpha_{LT}(\bar{\lambda}_{MT} - 0.2) + \bar{\lambda}_{MT}^2\right] \tag{4}$$

where $\bar{\lambda}_{MT}$ is the modified relative slenderness according to (1), α_{LT} is the imperfection factor corresponding to the relevant buckling curve.

The design buckling resistance moment ($M_{b,Rd}$) of a laterally unrestrained channel beam is thus taken for class 1 and 2 sections as:

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$$M_{b,Rd} = \chi_{LT} W_{pl,y} f_y / \gamma_{M1} = \chi_{LT} M_{ply.Rd} \tag{5}$$

The design rule became:

$$M_{Sd} \le M_{b,Rd} = \chi_{LT} M_{ply.Rd} \tag{6}$$

where M_{Sd} is the design bending moment due to the applied loading. $M_{ply.Rd}$ is the plastic moment capacity of the cross section along yy axis. In this way the effect of torsion is included in the Eurocode 3 design rules. This will be called the modified χ_{LT} method.

III. Finite Element Method

A commercial finite element software ANSYS [9], was used for the analysis. An eigenvalue analysis was used to get the deflected shape (mode shape or eigenvector) and the associated load factor (eigenvalue). The resulting eigenvalues are actually the load factors to be multiplied by the applied loading (1 kN/m^2), in order to obtain the critical buckling load.

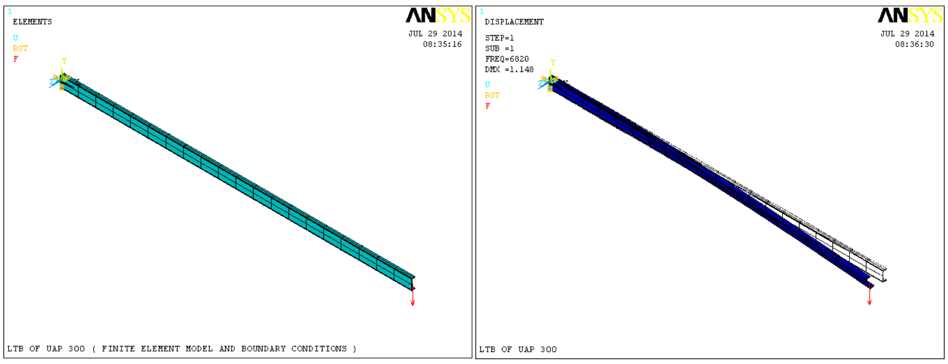
The element used in ANSYS [9], BEAM 188, is a quadratic three-dimensional beam element suitable for analyzing slender to moderately stocky beams. It possesses warping degrees of freedom, in addition to the conventional six degrees of freedom (Fig. 1). The numerical results of the buckling analysis are shown in Fig. 3, where the buckled shape and the load factor μ are indicated.

Fig. 3 depicts the behavior of the lateral torsional buckling, where lateral displacement combined with twisting can be observed.

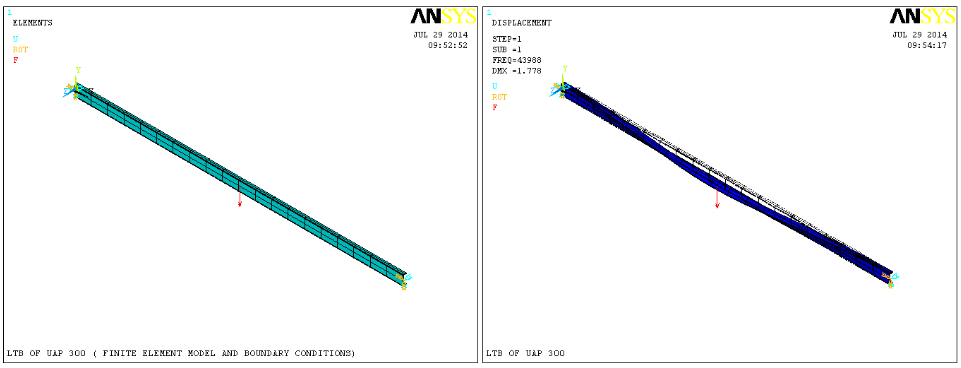
A. Validation

In order to validate the finite element model developed for this investigation, an eigenvalue buckling analysis was carried out for the models shown in Fig. 3, and the predicted load factors (Table I) were compared with the theoretical values of the lateral torsional buckling capacity. The difference between the results calculated using formula is: $\Delta = \dfrac{|\mu_{ans} - \mu_{theo}|}{\mu_{ansys}}$.

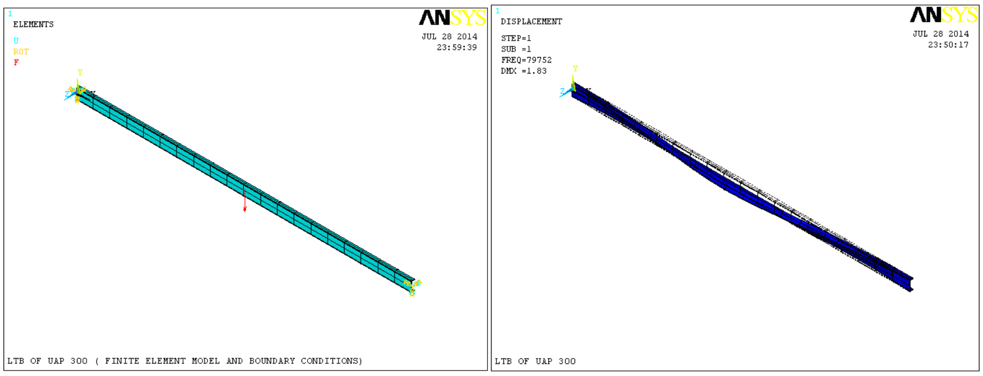
The buckling capacity predicted using the beam element BEAM 188 from ANSYS [9] is within 0.6% of the theoretical value.



(a)



(b)



(c)

Fig. 3 Numerical buckling analysis results: (a) Cantilever channel beam; (b) Simply supported channel beam; (c) Fixed end channel beam

TABLE I
PREDICTED LOAD FACTORS

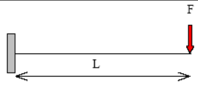
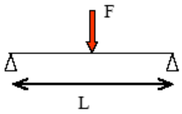
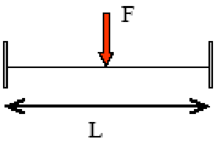
Section	Boundary conditions loading	Loading location	Load Factors μ_{theo}	Load Factors μ_{ans}	Load Factors Δ %
UAP 300	 Cantilever beam L = 6 m; F = -1.0 KN At beam fixing: v, θ, v', θ' (fixed)	Upper flange	6790	6820	0.43
		Shear center	7750	7800	0.64
		Lower flange	8360	8400	0.47
UAP 300	 Simply supported beam L = 10 m; F = -1.0 KN At beam fixing: v, θ (free); v', θ' (fixed)	Upper flange	43724	43988	0.60
		Shear center	44977	45000	0.50
		Lower flange	45793	46000	0.45
UAP 300	 Fixed end beam L = 10 m; F = -1.0 KN At beam fixing: v, θ (fixed) ; v', θ' (fixed)	Upper flange	79273	79752	0.60
		Shear center	80554	81000	0.55
		Lower flange	82170	82500	0.40

Fig. 3 shows the behavior of the lateral torsional buckling; we can notice the lateral displacement in combination with twisting.

IV. CONCLUSION

This paper compares ultimate lateral torsional buckling loads of unrestrained channel beams in bending based on adjusted design rules to ultimate loads obtained with Finite Element simulations. It can be concluded that the adjusted design method can lead to the underestimations of even less than 0.5% of the ultimate lateral torsional buckling load of unrestrained beams obtained from Finite Element simulations. The new design Method gives good results for lateral torsional buckling of steel channel beams loaded eccentrically without restraints between the supports.

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