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Numerical study of built-up double-Z members in bending and compression

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ABSTRACT

The use of the finite element method (FEM) for the design of composed, thin-walled, structural steel members is considered. The bolted double-Z frame member is an interesting and economical engineering solution, already used in practice [1]. However, the European recommendations for the design of steel structures do not consider built-up members from cold-formed steel profiles. Finite element analysis is used to capture the various buckling effects that shape the response of slender thin-walled members. From the finite element model, the importance of initial imperfections and stiffness of connections is identified. The experimentally validated model predictions show that a non-linear finite element analysis can predict the member behaviour, in terms of failure mode and ultimate load, yield line pattern, overall stiffness and local strain in the cold-formed profiles. To obtain a good prediction, overall and localised initial imperfections should be considered and included in the analysis.

1. Introduction

The cold-formed steel (CFS) industry has taken interest in innovative frame members, built-up from multiple thin-walled profiles. These could allow for structures with larger spans to be built, without changes in the manufacturing practice [1]. Design guidelines for CFS structural members under different types of loading are available in the European specification for steel structures [2,3]. These guidelines, however, cannot be applied to a composed member. They require that effective cross-section characteristics of the member be known, such as moments of inertia I_y and I_z, warping and torsion constants C_w and I_t, position of the shear centre. For a built-up member, only fictitious quantities could be derived for these, often through full-scale testing only. The predicted overall capacity can vary considerably, depending on the assumed cross-section characteristics. The North American standard has the same limitations—using the main part of the specification often results in inconsistent and unreliable predictions [4].

The studied cross-section (Fig. 1a) has already been used in building applications. The shape allows for frame members to be attached to each other easily (Fig. 2b and c). Another benefit is the lower transportation costs for asymmetrical Z-profiles [1]. In the design of such composed members, various aspects in the behaviour of the member within a steel frame should be taken into account, e.g., buckling, the interaction of internal forces in the member, the influence of the connection pieces on the buckling length and the boundary conditions, the slip in bolted connections, the sensitivity to imperfections, etc. Currently, no design method exists, even for the case of uniform compression.

In this paper, the finite element method is used to model members in pure compression and weak-axis bending. Numerical and experimental results are compared.

2. Literature review

The finite element method has been used to study the behaviour of single, as well as composed CFS structural members. The studied composed members, however, are of small scale and interconnected with self-tapping screws. Reasonable correspondence with experimental results has been reported, depending on the initial assumptions and complexity of the model.

General guidance for non-linear FEA of thin-walled members are given by Bakker and Peköz [5]. The authors emphasize on the importance of engineering judgement for determining the model input and for results interpretation. The effect of initial imperfections and residual stresses on the accuracy of computational models is addressed by Schafer and Peköz in [6]. The authors summarise a set of guidelines for the implementation of imperfections and residual stress in a numerical model. These include simple rules

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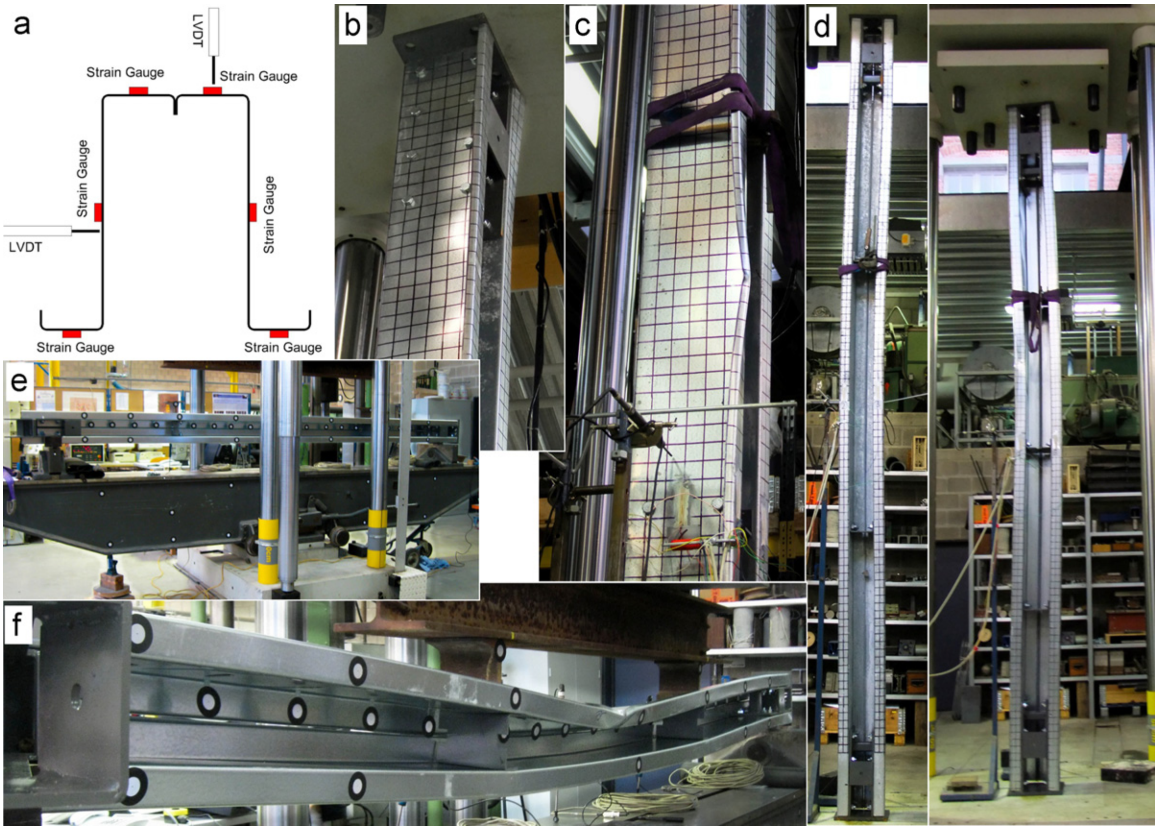

Fig. 1. Experiments: Columns: (a) cross-section and measurement equipment; (b) local buckling; (c) distortional buckling and yielding; (d) overall failure mode (torsional–flexural buckling) for two section sizes. Beams: (e) test set-up; (f) overall failure (distortional buckling).

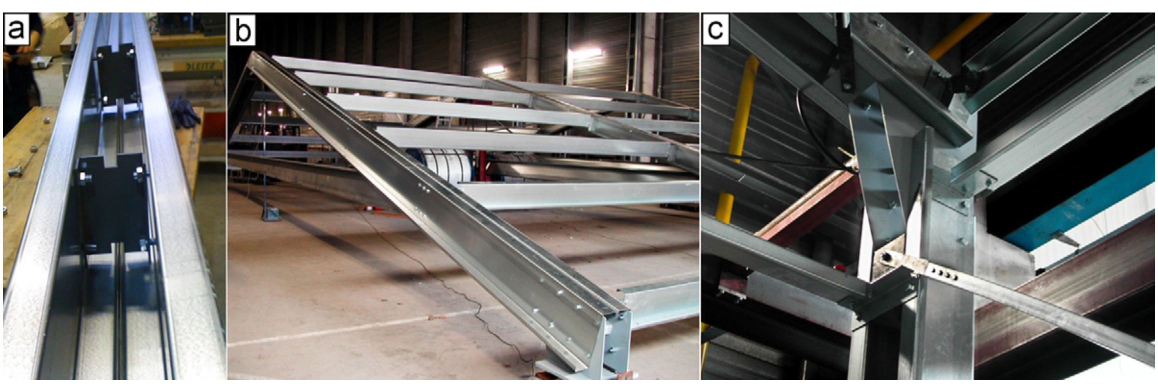

Fig. 2. Double-Z built-up CFS members; (a) assembly and intermediate spacers; (b) and (c) roof and eave joint in structures from Z-profiles.

of thumb for the amplitude of localised imperfections, as well as imperfection spectrums, based on existing experimental data. The spectrums allow for a quick assessment of the imperfection amplitude for a particular buckling wavelength.

Dubina and Ungureanu [7] studied the erosion of the theoretical buckling strength of CFS channels in bending and compression, due to initial imperfections in single and coupled instability failure modes. The analysis is based on non-linear FE simulations, from which the higher sensitivity of the distortional-overall interactive buckling to sectional imperfections is demonstrated.

Non-linear finite shell element models have been used by Shifferaw and Schafer [8] to calibrate the Direct Strength Method design expressions for beams, to account for the existing inelastic bending reserve in local and distortional buckling. The findings of the numerical investigations are validated based on experiments on C- and Z-section beams. The authors note an important distinction between members free to warp and members, in which warping is restricted.

Seo et al. [9] described complex LiteSteel beams, resembling channels with rectangular hollow flanges and slender webs with circular openings. These were studied using linear finite element solid models. Linear buckling analysis (LBA) was used to derive the elastic lateral-torsional buckling moments, needed for code-based predictions of the overall moment capacity. The authors proposed simplified modelling techniques, based on equivalent (reduced) web thickness, to account for openings in the web. The recommendations are to be used in approximate FE models or explicit elastic buckling numerical solutions, derived by the authors.

Narayanan and Mahendran [10] investigated distortional buckling in 16 innovative cross-section shapes for CFS columns (single profiles). Because the overall capacity, obtained based on the Australian design code, overpredicted the capacity of the columns