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Development of a consistent buckling design procedure for tapered columns

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ABSTRACT

EC3–EN 1993-1-1 provides several methodologies for the stability verification of members and frames. When dealing with the verification of non-uniform members in general, with tapered cross-section, irregular distribution of restraints, non-linear axis, castellated, etc., the code mentions the possibility of carrying out a verification based on 2nd order theory; however, several difficulties are noted when doing so, in particular when the benefit of plasticity should be taken into consideration.

Other than this, there are yet no guidelines on how to apply standardized, easily reproducible rules as those contained in Section 6.3.1 to 6.3.3 of the code to non-uniform members. As a result, practical safety verifications for these members are often carried out using conservative assumptions, not accounting for the advantages non-uniform members provide. In this paper, firstly, available approaches for the stability verification of non-uniform members are discussed. An Ayrton–Perry formulation is then derived for the case of non-uniform columns. Finally, and followed by a numerical parametric study covering a range of slenderness, cross-sections and fabrication process, a design proposal is made for the relevant case of in-plane flexural buckling of linearly tapered columns subject to constant axial force. The proposal is consistent with current rules for uniform columns provided in EC3-1-1, i.e., clause 6.3.1.

1. Introduction

The stability of uniform members in EC3-1-1 [1] is checked by the application of clauses 6.3.1 — stability of columns; clause 6.3.2 — stability of beams and clause 6.3.3 — interaction formulae for beam-columns.

Regarding the stability of a tapered member, clauses 6.3.1 to 6.3.3 do not apply and verification should be performed either by a cross-sectional verification based on second-order internal forces or, with some difficulties, according to clause 6.3.4 (the so-called "General Method", see [2,3]). Alternatively, as the most advanced but often practically not feasible variant, the resistance may also be checked by a numerical analysis that accounts for (geometrical and/or material) imperfections and (material and/or geometrical) nonlinearities, henceforth denoted as GMNIA.

However, for the "General Method", several difficulties are noted for the verification of a non-uniform member [4]. These are: (i) shape and magnitude of imperfections (geometrical and material); (ii) choice of an appropriate buckling curve and, as a result, of an adequate imperfection factor; (iii) definition of cross-section class; (iv) determination of cross-section properties for verification (or critical design location) — this problem also exists with respect to the application of clauses 6.3.1 to 6.3.3. For the application of advanced numerical analysis (GMNIA), besides the lack of guidance concerning the shape and magnitude of imperfections, the volume of work is still incompatible with practical application and a highly experienced engineer is required [5]. Moreover, there are no guidelines yet to overcome any of these issues.

In this paper, the case of columns subject to in-plane buckling with varying cross-section and with constant axial force is studied. It is the purpose of this paper to: (i) discuss the current difficulties in performing stability verification of non-uniform members; (ii) present the theoretical background for non-uniform columns; (iii) carry out a parametric study of FEM numerical simulations of non-uniform columns; and (iv) develop a proposal for the stability verification of in-plane buckling of tapered columns with constant axial force.

2. Available approaches for the stability verification of non-uniform members

2.1. General

Fig. 1(a) and (b) illustrates recent examples of the use of curved and tapered members or members with polygonal centroidal axis. The evaluation of the buckling resistance of such members lies outside the range of application of the interaction formulae of EC3-1-1 and raises some new problems to be solved.

Firstly, taking as an example the case of beam-columns (uniform or not) with varying ratios of M_{Ed} to N_{Ed} over the member length, the cross-sectional classification changes from cross-section to cross-

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