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Computational modelling of geometric imperfections and buckling strength of cold-formed steel

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ABSTRACT

Computational modelling of the buckling strength of cold-formed steel members as influenced by initial geometric imperfections is studied. The geometric imperfections are represented by the member eigenmode shapes. Along with the classical measure — the amplitude of imperfections, an energy measure defined by the square root of the elastic strain energy hypothetically required to distort the originally perfect structural element into the considered imperfect shape is used. Based on the measures, two approaches for the choice of the most unfavourable imperfections are suggested. Normalising imperfections by the amplitude, the energy measure is calculated as indicative parameter of imperfection significance. Vice versa, when adopting normalisation by the energy measure, the amplitude is used as a supporting parameter. The suggestions are illustrated on calculating the strength of an axially compressed steel lipped channel column with eigenmodes exhibiting local-distortional interactions. For eigenvalue and geometrically and materially non-linear strength calculations, the FEM codes MSC.NASTRAN and COSMOS/M are employed.

1. Introduction

The strength calculations of cold-formed steel are carried out at several levels of complexity depending on the purpose of its use. For the standardised design of ordinary members the effective width method and the recently developed direct strength method is applied. In conjunction with the latter one, more sophisticated analyses, e.g. the finite strip method or the generalised beam theory, can be applied. The most complete, however at the same time also the most computer time consuming and deep involvement requiring, is the use of analysis by the finite element methods (FEM). Particularly, this relates to the geometrically and materially non-linear FEM analysis of the strength of cold-formed steel with imperfections (GMNIA). As a consequence, the application of FEM GMNIA is mainly aimed at strength calculations of important structural members or parts.

A first attempt to codify the use of non-linear FEM for design purposes is given in the rules of EN 1993-1-5, cf. [1]. Currently, the ECCS TC7 working group TWG 7.5 “Practical improvements of Design Guidelines” is preparing a “TC7-recommendation” on the use of finite element methods for thin-walled members in order to further facilitate its use. Inclusion of basic principles, modelling and applications, especially the modelling of geometric imperfections for thin-walled structures is foreseen.

The development in cold-formed steel may be traced in recent review papers by Hancock [2], Dubina, Ungureanu and Rondal [3], Camotim, Basaglia and Silvestre [4], Schafer [5]. Valuable detailed study on solution sensitivities of computational modelling of elastic buckling and nonlinear collapse analysis for cold-formed steel members is presented by Schafer, Li and Moen [6].

Among the input parameters of the computational model of instability driven strength of cold-formed steel the shape and size of geometric imperfections play the crucial role, e.g. [3]. The imperfections are considered as initial shape deviations of mid-surface from the assumed perfect configuration. Generally, because of the lack of sufficient number of measurements allowing a statistical treatment of imperfection characteristics or in some cases lack of their adequacy, e.g. single component measurements may not be representative for the member imperfection shape, theoretical imperfections are employed. Commonly, eigenmodes of the elastic buckling problem calculated by FEM are used being natural choices associated with the strength problem. Having the same attribute, collapse shapes of the initially perfect member are sometimes applied. Also periodic modes — sine shapes are employed. However, for a complex profile an artificial merging of the imperfections of individual parts may arise. Other shapes are mostly combinations of those mentioned above.

The present paper aims at contributing to the guidance on the choice of the most unfavourable geometric imperfections, represented by the eigenmode shapes, for FEM GMNIA. Two imperfection measures are employed. The commonly used amplitude is accompanied with an energy measure derived from the hypothetic elastic strain energy of the

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