Numerical Analysis on Inelastic Buckling of Cold-formed Thin-walled Channel Column

†Lihua Huang ¹, Wenbin Yang[1], and Tingwei Shi[1]

[1]School of Civil Engineering, Dalian University of Technology, China

† Presenting and Corresponding author: lhhang@dlut.edu.cn

Abstract

Along with the development of technology and quality of steel, improving material utilization and saving natural resources have drawn more and more attention. Cold-formed thin-walled channel steel has the advantages of light weight, flexible molding, good mechanical performance, high efficiency section for bearing load, large overall stiffness and high seismic resistance, etc. It has been widely used in civil engineering, mechanical engineering, aerospace engineering and other fields.

The bearing capacity of cold-formed thin-walled members is mainly controlled by the stability conditions. The main failure modes include local, distorted, global and various forms of interactive buckling, in which elastic global buckling theories and methods have been well established for predicting the bearing capacity. As the wall thickness becomes thinner, local, distorted and related global inelastic buckling control the failure modes. Due to the influence of many factors, such as the form of section, size effect, large deformation, local material hardening and initial geometry and material defects, it is difficult to establish analytical theory for predicting inelastic buckling loads. The commonly used methods in engineering are semi-analytical methods: effective width method (EWM) and direct strength method (DSM). They are based on the combination of the stability theories of thin plates and beams with numerical analysis. EWM needs to divide the section into units, and uses effective width of design stress to calculate buckling loads. Since the effective width is a function of stress, and the stress distribution is associated with sectional geometry, the design method of the effective width needs to be continually iterations. But with the application of complex sections of thin-walled members, EWM becomes very complicated in the iterative process and inaccurate because of the interaction of units. DSM can be used to analyze distortion related buckling and also is suitable for solving components with complex sections, but its accuracy is lower in some cases. The effectiveness of finite element method (FEM) for analyzing nonlinear large deformation of plate and shell has been completely confirmed. FEM can be used not only to calculate the buckling loads, but also track the buckling and post-buckling path and simulate various buckling modes, which cannot be reflected by the semi-analytical methods. The implicit arc length method (ALM) proposed by Risk and developed by Powell, Simons and Crisfield has been programed in many finite element software and widely applied in nonlinear inelastic buckling analysis. Through tracking the balance path, the load-displacement relationship can be obtained before and after buckling. The accuracy and reliability of numerical method depend on many subjective factors, among which the application of initial defects is one of the main factors affecting the analysis results. Experiments show that buckling of thin-walled members is very sensitive to initial defects. The initially axial curvature will cause local buckling near the ends or the local and global interactive buckling of members. Material inhomogeneity may result in unevenly initial stiffness of cross section along the axis of a member, and the region of initial plastic deformation is undetermined. Besides, when the second-order effect is considered, the variable stress of the cross section will result in the change of sectional stiffness. Even for the same batch of specimens, the

failure modes caused by initial defects are often different. Therefore, in the numerical nonlinear buckling analysis for thin-walled member, the reasonable application of initial defects will be crucial to the accuracy of the calculation.
In this paper, numerical study on four cold-formed thin-walled flat channels with local and related global interactive buckling, and four edged channels with distorted and related global interactive buckling is carried out. The ultimate loads of the thin-walled channels with various buckling modes are calculated by using EWM, DSM and FEM software ABQUAS, respectively, and the accuracy and applicability of the three methods are analyzed through comparison with experimental results. It is shown that FEM is more stable than the EWM and the DSM in the calculation of various kinds of buckling problems. FEM has stronger universality and smaller average errors than the other two methods. When the first-order modal is taken as the initial defect and 1/1000 of the length as the defect coefficient, the ultimate loads from the conventional ALM are close to the experimental values, but the post-buckling performances and buckling modes are not completely the same as the actual members. Further research on the effects of initial defects shows that low order modal is suitable for local buckling analysis. But for the local and global interactive buckling problem, when the first three modals are taken as the initial defects, the calculation errors are all large. It means using initial defects in length will result low calculation accuracy for local and global interactive buckling. When 40% of the thickness is taken as the initial defect coefficient, the numerical results of local buckling are close to the experimental values. For local, distorted and global interactive buckling, the larger initial thickness defect is the lower limit of the longer member, while the smaller initial thickness defect is the upper limit of the shorter member. When the integral defects of the members in the fabrication process are considered, the initial angle defect can be applied in the numerical simulation. Usually the numerical results are ideal symmetric buckling modes, but the asymmetric buckling most often occurs in actual members, especially near constraint buckling. Due to the occurrence of elastic-plastic deformation in the process of buckling, the actual thin-walled compressive members are subjected from axial load to eccentric axial load. When the end constraint has great influence on the buckling of thin-walled members, the numerical model can be modified by applying a small initial angle defect. With the increase of the initial angle defect, the influence of constraints is more obvious, meanwhile, the local buckling region is moving to the ends and the loading capacity of the member decreases. Since the existence of some initial defects in actual members, it is suggested that the failure forms of thin-walled channel steels should be figured out first based on the semi-analytical methods, then the initial length, width or angle defects can be determined and applied in the numerical analysis to obtain the real buckling path and modes as the actual members.

Keywords: Cold-formed thin-walled channel column; Inelastic buckling; Numerical analysis;

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