Advances in Engineering Software 45 (2012) 349–359

Contents lists available at SciVerse ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Simulation of overall and local buckling behavior of cylindrical tubular members using fuzzy inference system

S. Nazary Moghadam [a], B. Asgarian [a,*], K. Nazokkar [b]

[a] Civil Engineering Department, K.N. Toosi University of Technology, No. 1346, Valiasr Street, Mirdamad Intersection 19967, P.O. Box. 15875-4416, Tehran, Iran
[b] Civil Engineering Department, Islamic Azad University, Central Tehran Branch, Tehran, Iran

ARTICLE INFO

Article history:
Received 10 April 2011
Received in revised form 7 September 2011
Accepted 16 October 2011
Available online 9 November 2011

Keywords:
Fuzzy system
Tubular member
Buckling
Finite element analysis
Plasticity
Large displacement

ABSTRACT

A fuzzy system has been developed to estimate the overall and local buckling behavior of cylindrical tubular members under monotonic axial compression. To train and test the fuzzy system, numerical data obtained from the finite element analyses is utilized. For this aim, a degenerate-continuum shell element which accounts for material and geometric nonlinearity is employed. Also, a least squares algorithm has been applied to determine the parameters of the fuzzy system such that the resulting fuzzy system accomplishes the desired performance. The proposed fuzzy system is capable of tracing the complete load-shortening relation and provides a tool for faster analysis.

1. Introduction

Information on the nonlinear behavior of tubular members is essential in relation to modern large-scale engineering applications such as offshore pipelines and platforms, land-based pipelines, and chemical and nuclear power plants. Perfect cylindrical tubes are structurally optimum sections for a column because they have a constant radius of gyration and consequently the same local and overall buckling strength in all directions. Also, the closed section of tubular columns has high torsional rigidity so torsional buckling is not a problem in these sections. On the other hand, tubular members, which are used in offshore structures, contain geometric imperfections such as out-of-roundness and out-of-straightness. In addition, typical diameter-to-thickness ratios and slenderness ratios for these members are in a range which indicates the potential for local buckling as well as overall buckling. Consequently, for a realistic assessment of strength and risk in offshore structures, the effect of local and overall buckling on the nonlinear behavior of cylindrical tubular members must be considered.

In general, the failure of a member in a structural system does not necessarily bring about the failure of the entire structural system. Instead, it may only cause a process of force redistribution. Therefore, the offshore structures which are subjected to the extreme environmental loadings such as earthquake and wave, are normally designed by their ultimate strength. As a result, for evaluating the energy absorption capacity of a cylindrical tubular member, studies are necessary not only on the behavior of the member up to its ultimate load, but also on its post overall and local buckling characteristics after inelastic buckling occurs.

The specific factors which are effective in overall and local buckling behavior of cylindrical tubular members are out-of-straightness of the member, out-of-roundness of the section, slenderness ratio (KL/r), diameter-to-thickness ratio (D/t), stress–strain curve and residual stresses. In particular, the increase in the diameter-to-thickness ratio brings about a sudden decrease in the energy absorption capacity of circular tubular members due to local buckling, and also the increase in the slenderness ratio decreases the maximum compressive load-carrying capacity as well as the energy absorption capacity of the circular tubular members.

During the last decade the overall and local buckling behavior of cylindrical tubular members has been the subject of intensive investigations. With regard to the need to laboratory data, for the establishment of refined criteria for design of cylindrical tubular members in offshore structures, appropriate laboratory tests have to be performed. In this respect, inelastic local and overall buckling behavior of tubular beam-columns has been studied experimentally by Sherman [1,2]. A series of over 100 tests of structural tubes was conducted in that research and a considerable amount of data was presented. Moreover, the development of efficient computational models for the material and geometric nonlinear analysis of circular tubular members has been one of the most important research activities. In this regard, extensive numerical research

* Corresponding author. Tel.: +98 21 88779623; fax: +98 21 88779476.
E-mail addresses: saeed_nazarimoghadam@yahoo.com (S. Nazary Moghadam), asgarian@kntu.ac.ir (B. Asgarian), kimianazokkar@gmail.com (K. Nazokkar).

0965-9978/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advengsoft.2011.10.011

has been carried out by Toma and Chen, Han and Chen, and Sohal and Chen. Toma and Chen [3] proposed an analytical model, in which the effect of residual stresses was included, to predict the inelastic overall buckling behavior of tubular members under the reversed loading condition. Han and Chen [4] presented a numerical method in which finite segment method was utilized to simulate the inelastic overall buckling response of tubular beam-columns under cyclic loading. Sohal and Chen [5] conducted a research on the local buckling behavior of circular tubular members under the reversed loading condition, through a simple kinematic model for cross-sectional deformation. In another research, a nonlinear fiber element capable of accounting for buckling and distributed plasticity for the simulation of post-buckling and cyclic behavior of tubular members was developed by Asgarian et al. [6–8]. In that research, the element was utilized to predict nonlinear behavior of jacket type offshore structures. Furthermore, nonlinear beam and shell finite elements have been of primary interest since the early history of nonlinear analysis of tubular members. In this regard, Karamanos and Tassoulas [9] studied the local buckling behavior of tubes using a nine-node shell finite element which takes into account large deformations as well as plasticity effects. Ju and Kyriakides [10] conducted research on the localized deformation of tubes in which a nonlinear shell finite element and the J_2-flow theory of plasticity with isotropic hardening were utilized. Skallerud et al. [11] presented an investigation on the cyclic capacity of tubular members using nonlinear beam and shell finite elements to simulate the effect of local and overall buckling. Moreover, works of Bardi and Kyriakides [12,13], Corona et al. [14] and Lee and Noh [15] are worth mentioning. In particular, a degenerated-continuum beam finite element which accounts for material and geometric nonlinearity proposed in [15] to simulate and investigate the inelastic buckling behavior of steel members under reversed loading. To sum up, nonlinear shell finite elements are powerful tools to analysis the material and geometric nonlinear behavior of tubular members, but they require long computation time.

Fuzzy systems are particular types of nonlinear functions which certain classes of them can approximate any functions with arbitrary accuracy. Indeed, Fuzzy systems determine a mathematical model, based on the concept of fuzzy set theory, for an unknown system by using its input–output data pairs. Zadeh [16] initiated the fuzzy theory by introducing the fuzzy set which is a generalization of the classical set. In contrast to a classical set which has a crisp boundary, belonging to a fuzzy set is characterized by a membership function which gives the fuzzy set flexibility to reflect the nature of human concepts. The fuzzy theory has been developed by various investigators, after realizing its potentiality in solving real world complex problems. Mamdani and Assilian [17] proposed a fuzzy system to establish the basic framework of fuzzy controller and applied it to control a steam engine as the first attempt to fuzzy control of a real system. Extensive research has been conducted by Takagi and Sugeno [18] and Sugeno and Kang [19] to propose a fuzzy system in which a systematic approach was developed to generate fuzzy rules from a given input–output data set. Over the past few years, the fuzzy set theory has been successfully applied to a wide variety of civil engineering and computational mechanics problems [20–24]. In particular, fuzzy systems have been largely and successfully applied to system modeling [25–28]. In this connection, Tsekouras et al. proposed a simple and fast algorithm to train fuzzy inference systems using numerical input–output data [29]. In conclusion, the above-mentioned capabilities make fuzzy systems a very powerful tool to estimate the nonlinear finite element analysis results with computationally less expensive algorithms.

In the present paper, attempts are made to propose a Mamdani–Assilian fuzzy system for estimating the overall and local buckling behavior of cylindrical tubular members under a variety of slenderness ratios and diameter-to-thickness ratios. To train and test the fuzzy system, input–output data pairs related to overall and local buckling behavior of tubular members should be provided. These data are obtained by performing finite element analyses, using a nonlinear shell finite element, for various slenderness ratios and diameter-to-thickness ratios. Also, a least squares algorithm has been applied to optimize the fuzzy system parameters. The approach presented in the following has the capability of determining the ultimate compressive strength and estimation of post-overall buckling as well as post-local buckling behavior of tubular members by tracing the complete load-shortening relation which can be used in nonlinear analysis of jacket type offshore platforms and provides a tool for faster analysis. The predicted overall and local buckling behavior by the fuzzy system was found to be in a good agreement with finite element results.

2. Finite element analysis

In order to investigate the overall and local buckling behavior of cylindrical tubular members, the consideration of geometrical and material nonlinearity is of vital importance. Therefore, an appropriate shell element which can accurately represent nonlinear behavior of tubular members should be chosen. Probably the majority of investigations on nonlinear shell elements have followed on from the linear shell element proposed by Ahmad et al. [30] using the degenerate-continuum approach [31–34]. The degenerated shell element is developed by imposing the same kinematical constraint as those of the Reissner–Mindlin theory on a continuum element. In this paper, an 8-noded degenerated shell element has been used for modeling the overall and local buckling behavior of cylindrical tubular members. The formulation of Ramm and Matzenmiller [33], which is also described in the finite element book by Crisfield [35], has been followed closely to formulate the degenerated shell element.

2.1. Kinematics of shell element

According to the 8-noded degenerated shell element shown in Fig. 1, two vectors are required to define the geometry of the shell element. One vector is needed to express the configuration of the shell middle surface and another vector to express any position between the top and bottom surface of the shell in the thickness direction. Consequently, the configuration of this shell element can be interpolated via

$$\begin{Bmatrix} x \\ y \\ z \end{Bmatrix} = \sum_{i=1}^{8} h_i(\xi,\eta) \begin{Bmatrix} \bar{x}_i \\ \bar{y}_i \\ \bar{z}_i \end{Bmatrix} + \frac{\zeta}{2} \sum_{i=1}^{8} h_i(\xi,\eta) a_i \begin{Bmatrix} V_{ix} \\ V_{iy} \\ V_{iz} \end{Bmatrix} \quad (1)$$

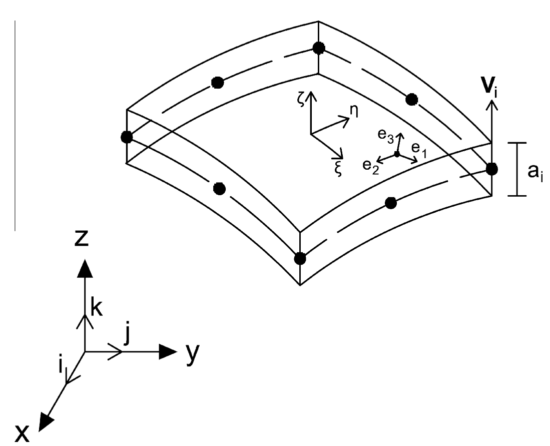

Fig. 1. The 8-noded degenerated shell element.