Application of a Beam-Column Element Formulation for Ultimate Strength Analyses of Thin-Walled Structures

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ABSTRACT

In this paper, the collapse behavior of symmetric thin–walled beams is investigated. An appropriate beam–column element formulation is presented for progressive collapse analyses of beam structures under different kinds of loads. The element behavior is validated by experimental results. Therefore, a Hydraulic Test Rig for Structural Components at University of Rostock was used. Details of the Hydraulic Test Rig as well as the arrangement of different bending experiments are explained within this paper. Additionally nonlinear finite element analyses are performed for validation purpose.

KEY WORDS: Beam–Column Element; Bending; Collapse Analysis; Finite Element Analysis (FEA); Thin–Walled Structure; Ultimate Strength.

INTRODUCTION

Ships and offshore structures are subjected to various types of loads during their lifetime. Especially under harsh operational and environmental conditions the loads can reach extreme values. To ensure the safety of large structural systems the prediction of ultimate strength is necessary. To evaluate the ultimate hull girder strength of a ship under longitudinal bending different methods exist. The strength reduction of structural members can only be simulated by progressive collapse analysis methods. Under consideration of material and geometrical nonlinearities a progressive collapse analysis of large structural systems by using the Finite Element Method (FEM) is still a very time consuming procedure. Therefore the Idealized Structural Unit Method (ISUM) was developed to reduce the computational time. In the newest ISUM formulation proposed by Fujikubo and Kaeding (2002) a combined model of ISUM plate and beam–column elements was developed to predict the ultimate strength of large structural systems composed of stiffened plate panels. The applicability of the combined ISUM–plate/beam–column element model (Fujikubo et al., 2002; Fujikubo et al., 2005; Kaeding and Fujikubo, 2002; Kaeding and Fujikubo, 2003; Kaeding et al., 2005) is demonstrated for several structural systems.

For further improvements of the combined ISUM–plate/beam–column element model the applicability of the beam–column element formulation for collapse analyses of thin–walled structures has to be investigated. In general any beam–column element which can cope with the effects of warping and large deflection can be employed in combination with the ISUM plate elements. Here, the beam–element is based on a displacement formulation using the kinematic relationships proposed by Matsumoto et al. (1981). Based on the nonlinear kinematic and constitutive relationships, appropriate shape functions and the application of the principle of virtual work in incremental form the element stiffness matrix is presented. Furthermore, the applicability of the element formulation is extended to symmetric I–profiles.

Within this paper the beam–column element formulation is applied to symmetric thin–walled beams: For different open sections (IPE300, HEB260, HEM220) progressive collapse analyses are performed to estimate their load carrying capacity. The beam structures are subjected to 3–point bending and 4–point bending about the strong axis until ultimate strength is reached. To simulate the warping effect, the IPE300 girder is clamped at one side and loaded by constant torsion moment at the other side exemplarily. For validation purpose of the beam–column element formulation additional Finite Element Analyses (FEA) are performed. The nonlinear behavior of open section beams under different kind of loads is also investigated numerically by Mohri et al. (2002) and Mohri et al. (2007). Even a 3D finite beam element with seven degrees of freedom per node was developed by Mohri et al. (2008) for non–linear analyses of thin–walled structures.

The beam–column element used in this paper is validated against experimental data. Therefore a Hydraulic Test Rig System for Structural Components at the University of Rostock was used to perform 3–point and 4–point bending tests. This testing system has a length of 6m, width of 2.5m and total height of 5.85m. Static loads up to 1300kN and dynamic loads can be applied. Further details of the Hydraulic Test Rig System as well as the arrangement of the bending tests are explained within this paper. The numerical results are validated against the experimental load–displacement curves.