ELSEVIER

Thin-Walled Structures 37 (2000) 77–95

THIN-WALLED STRUCTURES

www.elsevier.com/locate/tws

A Koiter's perturbation strategy for the imperfection sensitivity analysis of thin-walled structures with residual stresses

A.D. Lanzo *

DiSGG, Università della Basilicata, 85100 Potenza, Italy

Received 1 January 1999; received in revised form 13 January 2000; accepted 31 January 2000

Abstract

This paper suggests a strategy for the imperfection sensitivity analysis of elastic thin-walled structures with notable residual stresses. The analysis is carried out by means of a Koiter's perturbation approach. The concept of imperfection, traditionally associated with geometric and load factors, is extended in this paper to the residual stresses. The strategy is implemented in a FEM code. A comparison of the obtained results allows a discussion on the accuracy and the influence of the different coefficients connected to the asymptotic analysis of the residual stresses. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Elastic stability; Imperfection sensitivity analysis; Perturbation method; FEM; Thin-walled structures

1. Introduction

In the analysis of the critical and post-critical behavior of elastic structures, the role of the initial residual stresses of the manufacturing processes is generally considered only through the influence of the initial deflections induced from them (first-order imperfection sensitivity, see [1]). The analysis of metallic thin-walled structures obtained by a special process of assemblage and welding of the panels [2] instead deserves a different discussion. This kind of structure is practically unaffected by initial deflections, whereas the initial residual stresses can have very relevant values,

* Corresponding author. Tel.: +390-971-205055; fax: +390-971-205070.
E-mail address: lanzo@disgg.unibas.it (A.D. Lanzo).

PII: S0263-8231(00)00008-2

of the same order as the buckling critical stresses, and such as to affect the critical and post-critical behavior of the structures: therefore they have to be considered directly in the analysis (second-order imperfection sensitivity).

Nevertheless to be modelled into an analysis strategy, the residual stresses must discount the aleatory character of their distribution, as the analysis has to be performed for a fairly wide spectrum of possible distributions. Because of the high computational costs, it penalises incremental-iterative strategies of analysis: the residual stresses being an initial datum of the problem, the analysis of the structure must be performed ex-novo for each new possible distribution. The fundamental feature required for an optimal analysis strategy is that the influence of the residual stresses can be valued after the structure analysis in the absence of residual stresses, with negligible additional cost. The treatment of the *imperfections* in the perturbation strategy of analysis based on Koiter's theory of elastic stability is well-suited to this approach [3–6].

This analysis strategy is articulated in two distinct phases. In the first phase the behavior of the structure in absence of imperfections (the *perfect* structure), typically connected to bifurcations of the relative equilibrium paths, is analyzed. In the second phase the influence is considered, especially in terms of load carrying capacity, of all those factors (the imperfections) that contaminate the scheme of perfect structure, generally evolving the bifurcative character of the behavior in a phenomenology of snapping and limit load. It is the first phase of the analysis that requires higher computational costs (they are substantially equivalent to a linear stability analysis and then, in any case, of some lower orders of an individual step-by-step analysis), reducing the last phase to the evaluation of some scalar coefficients and to the resolution of a nonlinear algebraic system with a reduced number of equations. This simplicity in dealing with additional imperfections compensates the aleatory character of their distribution, the analysis being capable of repetition for a fairly wide spectrum of possible imperfections with additional negligible costs. In this scheme, the imperfection sensitivity analysis is therefore performed in an effective way.

Imperfections are traditionally associated with geometric and load factors. The aim of this paper is to extend the concept of imperfection of Koiter's theory to the residual stresses, leading again to the simplicity and efficiency of an imperfection sensitivity analysis of the perturbation strategy.

The paper is organized as follows. The fundamental lines of a perturbation strategy oriented to the FEM analysis of thin-walled structures, presented by the author in Refs [7–14], are initially summarized. Afterwards the presence of residual stresses, with reference to membranal states, is brought within a variational formulation based on the stationary condition of the total potential energy and then framed in the perturbation strategy of imperfection sensitivity analysis. In particular the energy contributions connected to the residual stresses are represented by means of additional terms, while the influence is evaluated with coefficients (of imperfection) to the several perturbation orders of the equilibrium equations of the structure. Finally, the quantitative weights of such coefficients are tested with reference to some sample problems, giving some practical indication of their treatment within a FEM-perturbation analysis algorithm.