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SCIENCE DIRECT
Thin-Walled Structures 43 (2005) 499–514
THIN-WALLED STRUCTURES
www.elsevier.com/locate/tws

Dynamic buckling of fiber composite shells under impulsive axial compression

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Received 19 December 2003; accepted 27 July 2004
Available online 22 October 2004

Abstract

The paper deals with dynamic buckling due to impulsive loading of thin-walled carbon fiber reinforced plastics (CFRP) shell structures under axial compression. The approach adopted is based on the equations of motion, which are numerically solved using a finite element code (ABAQUS/Explicit) and using numerical models validated by experimental static buckling tests. To study the influence of the load duration, the time history of impulsive loading is varied and the corresponding dynamic buckling loads are related to the quasi-static buckling loads. To analyse the sensitivity to geometric imperfections, the initial geometric imperfections, measured experimentally on the internal surface of real shells, are introduced in the numerical models. It is shown numerically that the initial geometric imperfections as well as the duration of the loading period have a great influence on the dynamic buckling of the shells. For short time duration, the dynamic buckling loads are larger than the static ones. By increasing the load duration, the dynamic buckling loads decrease quickly and get significantly smaller than the static loads. Since the common practice is to assume that dynamic bucking loads are higher than the static ones, which means that static design is safe, careful design is recommended. Indeed, taking the static buckling load as the design point for dynamic problems might be misleading.

Keywords: Dynamic buckling; Finite element analysis; Fiber composite cylindrical shells; Impulsive axial compression; Geometric imperfections

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0263-8231/$ - see front matter
doi:10.1016/j.tws.2004.07.012

1. Introduction

The stability of composite cylindrical shells is of fundamental interest in aircraft and missile design as thin-walled cylindrical shells have constituted primary structural parts for many years and because the composite materials are nowadays extremely attractive due to their considerable strength-to-weight ratio. They are subjected to various loading both static and dynamic. The investigations in the past two decades were primarily confined to the static stability. This effort has led to a reasonably good understanding of the response of the composite shells to static loading, including the effects of initial geometric imperfections and lamina stacking sequence.

However, dynamic buckling is not yet clearly defined. It relates to the behaviour of the structures subjected to pulse loads, and represents the loss of stability or the deformation of a structure to unbounded amplitudes as the result of a transient response to an applied impact loads.

Analytical work on dynamic buckling problems for axially loaded cylindrical shells was first carried out by Volmir [1], who obtained solutions of a two degrees of freedom system using Galerkin's method. Then Coppa and Nash [2] and Roth and Klosner [3] used the potential energy method to study a limited degrees of freedom system, Karagiozova and Jones [4] studied a multi-degrees of freedom model for dynamic buckling of an elastic–plastic structure, while Tamura and Babcock [5] analysed the dynamic buckling of cylindrical shells with geometric imperfections, applying the Budiansky–Roth criterion [6]. More recently, Simitses [7] investigated the effect of static preloading on the dynamic critical loads; Lindberg [8] summarised and demonstrated the range of applicability of two dynamic buckling criteria choosing as example a cylindrical shell under dynamic pulse axial loads from nearly impulsive loads to step loads of infinite duration; Gilat et al. [9] analysed the axisymmetric response of nonlinearly elastic cylindrical shells subjected to dynamic axial loads using an incremental formulation.

Finite element analyses were carried out by Mustafa et al. [10] for the prediction of the dynamic buckling response of thick tubes of various lengths, incorporating an idealised geometric imperfection in the radius, and by Pegg, who investigated the dynamic pulse buckling of infinite cylinders of various radius to thickness ratios [11] and of ring-stiffened cylinders [12], using the code ADINA.

Very few experimental data can be found in literature, regarding dynamic buckling. Abramovich and Grunwald [13] performed an experimental test series on laminated composite plates, while Cui et al. [14] investigated the elastic–plastic dynamic buckling properties of rectangular mild steel plates under in-plane fluid–solid slamming. Zimcik and Tennyson [15] investigated experimentally the dynamic response of thin-walled circular cylindrical shells (with and without controlled initial shape imperfections) to transient dynamic square-pulse loading of varying time duration. Yaffe and Abramovich [16] investigated, both numerically and experimentally, the buckling of aluminium cylindrical stringer stiffened shells under axial dynamic applied loading. But, until now, no test results were obtained to form a sound experimental database for this phenomenon.

There are then few works concerned with dynamic buckling of composite cylindrical shells and they do not cover all the fundamental aspects of the composite shells.