Impact-induced nonlinear damped vibration of fabric membrane structure: Theory, analysis, experiment and parametric study

Changjiang Liu, Xiaowei Deng, Jian Liu, Zhoulian Zheng

PII: S1359-8368(18)32559-9

DOI: 10.1016/j.compositesb.2018.09.078

Reference: JCOMB 6048

To appear in: *Composites Part B*

Received Date: 11 August 2018

Revised Date: 7 September 2018

Accepted Date: 24 September 2018

Impact-Induced Nonlinear Damped Vibration of Fabric Membrane Structure: Theory, Analysis, Experiment and Parametric Study

Changjiang Liu [1], Xiaowei Deng [2,*], Jian Liu [1], Zhoulian Zheng [3]

[1] School of Civil Engineering, Guangzhou University, Guangzhou 510006, China

[2] Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong, China

[3] School of Civil Engineering, Chongqing University, Chongqing 400045, China

(* Corresponding author: e-mail: xwdeng@hku.hk)

Abstract. Fabric membrane, a typical composite material, is widely applied in building structures, agricultural facilities, packaging engineering, and aeronautical engineering, etc. However, it may fail subject to large-amplitude vibration induced by impact due to its lightweight and small stiffness properties. Herein, the nonlinear damped vibration of a pretensioned rectangular orthotropic membrane structure under impact loading is studied by analytical, numerical and experimental methods. The governing equation is derived based on the von Kármán large deflection theory, and the analytical solution is obtained by the Bubnov-Galerkin method and the Krylov-Bogolubov-Mitropolsky (KBM) perturbation method. Meanwhile, the numerical and experimental analysis are carried out for validation of analytical model and good agreement is achieved. Furthermore, parametric study is also performed to find the sensitivity of the design parameters to the vibration response. The results obtained in the paper lay solid foundation for the vibration control and dynamic design of orthotropic membrane structures.

Keywords: Orthotropic membrane; Nonlinear vibration; Impact loading; Perturbation method; Numerical analysis

1. Introduction

Orthotropic membrane is used in a wide variety of engineering applications spanning from aerospace and civil structure to biomechanical device because of its tunable stiffness and light weight) [1-3]. However, such composite structure is very sensitive to impact loads, and thus is easy to induce large vibration under impact loading which may lead to structural failures) [4-8]. The objective of this paper is to investigate the nonlinear vibration of orthotropic membrane under impact, which may result in significant consequences for safety design.

Membrane analyses have a rich history. In the seventeenth century, the researchers laid the physical foundation and provided initial mathematical tools to deal with the vibration problems. By the eighteenth Century, vibration mechanics had gained independence from physics, and the most important achievement is the formation of linear vibration theory; in 1829, Poisson solved the linear free vibration problem of thin membrane (Chen and Liu, 1997) [9]. More generally, however, the vibration of the membrane is considered nonlinear; therefore, the nonlinear vibration problem of membrane has been extensively studied. Nagaya (1978) [10] investigated the vibration problem of an arbitrary-shaped membrane by Fourier expansion and Laplace transform method. This provides the basis for the other in-depth studies on the vibration and dynamic responses of membrane structures. Thereafter, Qian (1982) [11] studied the vibration of rectangular, circular and elliptical membrane with unequal tension in two directions and obtained the approximate solution of the free vibration frequency of the membrane. Yuan and Zhang (1993) [12, 13] explored the large deflection and free vibration problem of membrane by the finite element method of lines. York et al. (1999) [14] extended the material-point method (MPM) and exhibited significant improvement over existing methods in handling membrane problems. Ersoy H. et al. (2009) [15] developed a method of discrete singular convolution to investigate the free vibration of circular and annular membranes with varying density, which showed well agreement with the analytical and numerical results of other researchers. The nonlinear vibrations of nano-sized membranes without initial tension were studied using analytical and finite element method by Bao et al. (2004) [16], and then the analytical solution of free vibration of annular membrane was obtained by Lin et al. (2008) [17]. Zheng and Liu et al. (2009[18], 2010[19], 2013[20, 21]) considered the geometric nonlinearity of membrane and studied the vibration problem of orthotropic membranes by large deflection theory and perturbation methods. Chucheepsakul et al. (2009) [22] provided an alternative approach for large deflection analysis of the orthotropic membranes subject to gravitation,