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Review

Dynamic response of rectangular prestressed membrane subjected to uniform impact load

Dong Li [a], Zhou-Lian Zheng [a,b,c,*], Cao-Yu Liu [d], Guang-Xin Zhang [a], Yong-Sheng Lian [a], Yuan Tian [a], Yang Xiao [a], Xiao-Meng Xie [a]

[a] School of Civil Engineering, Chongqing University, Chongqing 400045, China
[b] Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China
[c] Chongqing Jianzhu College, Chongqing 400072, China
[d] Urban Railway and Architecture Design Institute (China Railway First Survey & Design Institute Group Co., LTD.), China

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ABSTRACT

This paper investigated the dynamic response of rectangular prestressed membrane subjected to uniform impact load theoretically and experimentally. The dynamic response proceeds in two stages, namely, forced vibration and free vibration. Firstly, the maximal displacement for forced vibration is obtained by means of the principle of minimum potential energy based on the theoretical model proposed. Then, equations of motion for the transverse free vibration are derived based on thin-plate theory, and simplified by using Galerkin method. Consequently, the analytic solutions of dynamic parameters, such as frequency, displacement, amplitude, velocity, and acceleration, for free vibration are obtained by means of the multiple-scale perturbation method. In order to identify the reliability of theoretical model, the corresponding experimental study is carried out based on the developed experimental system. Furthermore, the effects of pretension force and load on the dynamic response of membrane are discussed, respectively. The present work provides a theoretical model to calculate the dynamic response of prestressed membrane subjected to uniform impact load, and a set of experimental system to study this problem.

1. Introduction

Prestressed membrane have received considerable attention in recent years due to their applications in dozens of engineering application, such as space applications, solar thermal propulsion and civil engineering structures [1,2]. These structures own many advantages like being thin, light, flexible, and translucent. However, they are vulnerable to vibrate violently under uniform impact load such as wind and rain owing to their feeble stiffness, lower frequency and small damping, which may result in collapse of membrane

* *Corresponding author at*: School of Civil Engineering, Chongqing University, Chongqing 400045, China.
E-mail address: zhengzl@cqu.edu.cn (Z.-L. Zheng).
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structures [3,4]. Therefore, it is essential to study the vibration characteristic of prestressed membrane under uniform impact load in order to provide some references to safe design.

Until recently, there are some researches on the mechanical properties of prestressed membrane under uniform load. Seide [5] established the large deflection equations for uniformly loaded membranes with the expanded deflection function in Fourier series. Results for the center normal deflection were obtained after an iterative procedure for nonlinear equations. Storakers [6] utilized Merson's version of the Runge–Kutta integration procedure to solve the equations for circular membrane under uniform pressure. The laws of deflection varying with radius and Poisson ratio were discussed. Trotsenko [7] applied variation methods solve the problem concerning small oscillations of a circular membrane subjected to a uniform stress state. Then, the deflection of membrane and natural frequencies of membrane can be determined. Steinmann et al. [8] solved the mechanical problems of orthotropic sensor membranes under uniform external pressure combining a Ritz method and Hermite polynomials. Furthermore, the deflection and eigenvalues results were presented. Zhang et al. [9] investigated the mechanical properties of membrane structures under static loading with a systematic series of tests and finite element analysis. The effects of loading history on the mechanical properties can be found. Lim [10] provided a specific semi-empirical model to calculate the deflection of circular membranes under uniform load. In addition, the effects of Poisson ratio of material on the deflection of circular membrane were discussed.

In a word, many scholars concentrated in theoretical researches on the static problems of prestressed membrane under uniform load. However, the study on the dynamic response of membrane under uniform load is little, especially the uniform impact load. Furthermore, the membrane is more vulnerable to uniform impact load, such as turbulent wind, falling objects and blast load, than uniform static load during their service life. The uniform impact load can lead to the relaxation and tear in membrane due to the large deflection in dynamic response, which may cause engineering accidents [11,12]. Thus, it is worth studying the dynamic response of prestressed membrane under uniform impact load both theoretically and experimentally.

This paper presents an analytical method to study the problem concerning the dynamic characteristics of orthotropic rectangular prestressed membrane under uniform impact load. The dynamic response is divided into two stages: forced vibration and free vibration. Firstly, the analytical solutions of maximal displacement for forced vibration are derived by means of the principle of minimum potential energy based on the theoretical model proposed. Then, the nonlinear equations for free vibration are established using the Von Kármán large deflection theory, and simplified by Galerkin method. The analytical solutions of free vibration can be obtained with the multiple-scale perturbation method solving the simplified equations. Finally, a series of experiments are conducted to validate the reliability of theoretical solutions. Furthermore, the effects of parameters such as pretension force and load on the dynamic response of prestressed membrane are analyzed.

2. Theoretical study

2.1. Formulation of the problem

Consider a homogeneous, orthotropic prestressed rectangular membrane of thickness h and area with the length of $2a$ and the width of $2b$, as shown in Fig. 1. The pretension force along the directions of x and y is N_{0x} and N_{0y}, respectively.

It is assumed that the uniform impact load is the mass of homogeneous intensity ρ^* and area with the length of $2a^*$ and the width of $2b^*$. The center of uniform impact load coincides with the center of membrane, namely (0,0). Both membrane

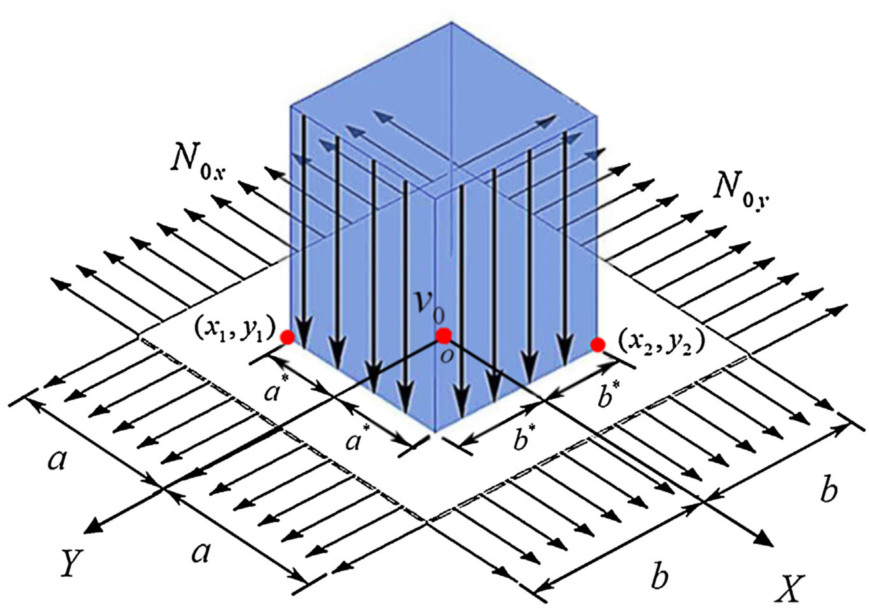

Fig. 1 – The model of orthotropic prestressed rectangular membrane under uniform impact load.