화이트 노이즈 음파를 이용한 막구조물의
장력 측정장치 개발

Development of Measurement Equipment of Membrane Stress Using White Noise Sound Wave

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요 약

회악이나 압축에 저항할 수 없는 막재료에 적절한 장력을 부여함으로써 안정화 되는 막구조물은, 유지 관리면에 있어서 막판
에 도입되어 있는 장력을 설계대로 유지하는 것이 매우 중요하다. 톨로막에 도입되어 있는 장력을 정확하게 파악하기가
 어렵다. 제작품, 적응모형의 설계를 가지는 막을 가정한 음파를 이용해 진동시키고, 진동하는 막의 고주파음수를 측정함으로
 서 급격적으로 막장력 측정하는 방법을 제안한다. 막을 진동시키는 음파로서 정현파와 화이트 노이즈를 이용해 검증실험을
 해 본다. 본 논문은 주요 막재료를 이용해 행한 막장력 측정 이론의 검증을 위한 실험 결과로, 설계하는 막구조물의 장력측정
을 통해, 본 측정장치의 정확성과 폭 넓은 적용성 및 측정에 있어서의 안정성을 검증한다.

Abstract

One of the most important matters in keeping membrane structures in healthy condition is to maintain the proper tension
distribution over the membrane. However, it is not easy to know the real stress level in the membrane quantitatively after
completion of the structures. Authors suggested measurement method that can measure membrane stress using sound wave,
and have been holding experimental tests of membrane stress measurement that used the sound external excitation with sine
wave and white noise. The concept of the method is the fact that measurement of resonance frequency by vibrating membrane
having rectangular boundary by audible frequency can measure membrane stress indirectly. In this paper, through the
experimental tests it is proved that the equipment can be used for not only the membrane material of type A but also for types
B and C. In addition, it is proved that the developed measurement equipment is available to stably measure the membrane
stress which exists in the membrane material of the actual membrane structures.

키워드 : 막장력측정, 음파진동, 화이트노이즈, 현장측정

Keywords : Measurement of membrane stress, Sound excitation, White noise, Practical measurement

1. Introduction

Membrane structure is a structure that used membrane materials which cannot afford compression or bending,
but is stabilized by maintaining appropriate tensile status, and thus able to endure load like snow or wind, etc.
These membrane structures need accurate maintenance

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of tension condition but generally it is difficult. After
the completion of construction, measuring stress of
membrane structures is very important in the maintaining
point of view, and huge expect is putted on this measuring
technology.

Up to recent years, several methods on measurement
of membrane stress have been proposed and some have
been used in a construction site, where precise
measurements of membrane stress have been tried,
however, accuracy of the obtained data has been found
to be far from desirable one. Such situation has not
been changed until recent days, and we do not have the measurement tools yet on which we can actually depend. Moreover, due to the different properties in biaxial directions for material of membrane, the stress in the warp direction is generally different from that in the fill one. We have not yet had such practicable device by which membrane stress in both directions can be measured even roughly.

Authors suggested measurement method that can measure membrane stress using sound wave, and have been holding experimental tests of membrane stress measurement that used sine wave and white noise as external excitation\(^1\)\(^-\)\(^3\). As shown in Fig. 1, the concept of the method is the fact that measurement of resonance frequency by vibrating membrane with rectangular boundaries as shown Fig. 2 by audible frequency can measure membrane stress indirectly. This is a basic concept, but from the research we realized that natural frequency of membrane is affected by air. That is because the vibrating membrane is as light as air. For estimation of theoretical natural frequency, the effect of added mass of air has to be considered. Thus by replacing vibrating surface of membrane to the circular plate having the same area, we estimated added mass by air theoretically\(^4\)\(^-\)\(^5\).

In experimental test conducted by using white noise which has frequency field of 0 to 500Hz as an external excitation to measure membrane stress, verification experiments are held such as weighting upper part of equipment, improving power of speaker, sticking rubber to the base of the equipment and sharpened boundary of acrylic box\(^6\)\(^-\)\(^8\). In addition, for practical use of equipment, we have held experimental tests to verify the effectiveness of improved equipment for high accuracy\(^6\)\(^-\)\(^8\).

In this paper, it is proved that the equipment can be used not only the membrane material of type A for membrane structure but also types B and C through the experimental tests. Moreover, result of the measurement of existing frame supported membrane structure covered with the membrane material of type A is reported.

2. Fundamental Theory

The equation of motion of the membrane can be expressed as the following equation,

\[
-p_o \frac{\partial^2 \omega}{\partial t^2} + \left( \frac{\partial^2 \omega}{\partial x^2} T_x + \frac{\partial^2 \omega}{\partial y^2} T_y \right) = p
\]

(1)

where \(\omega(x, y, t)\) is the deflection of membrane over the surface, \(t\) is the time, \(p\) is the external pressure, \(\rho_o\) is the mass of membrane per unit area and \(T_x\) and \(T_y\) represent the existing tension per a unit length in \(x\) and \(y\) directions, respectively. Let us assume that