구조용 케이블의 장력 변화에 따른 정착부의 임피던스 특성에 대한 유한요소해석

Finite Element Analysis on Impedance Parameters of Anchor Plate of Structural Cables Under Cable Force Changes

Nguyen, Khac-Duy* • 박 재 형** • 홍 동 수*** • 이 주 원**** • 김 정 태***** • 나 원 배******
Nguyen, Khac-Duy • Park, Jae-Hyung • Hong, Dong-Soo • Lee, Ju-Won • Kim, Jeong-Tae • Na, Won-Bae

Abstract

This paper presents a finite element analysis on impedance parameters of anchor plates of structural cables under the change in cable forces. To achieve the objective, four approaches are implemented as follows: Firstly, theoretical background of electro-mechanical impedance is described. Secondly, anchor plates of structural cables are selected to experimentally examine the relationship between impedance parameters and cable force changes. Thirdly, finite element analysis is performed to verify the experimental results. Fourthly, a comparison between the experimental and numerical analysis on impedance parameters of anchor plate of structural cables under cable force changes is carried out.
keywords : PZT, impedance-based, structural health monitoring, structural cable, finite element.

1. Introduction

The impedance-based method was first proposed by Liang et al. (1994). Since then, many researchers have improved the method and applied the method to various damage detection problems. The method utilizes high-frequency structural excitations, which are typically higher than 30 kHz through surface-bonded PZT patches to monitor changes in structural mechanical impedance. In this method, PZT patches can act as both sensors and actuators based on their electro-mechanical coupling.

To monitor the multi damage on concrete beam, Park et al. (2006) presented a finite element - based method on comparing with experimental study utilizing the PZT impedance signatures. Also, Giugiutiu and Zagrai (2002) assessed the agreements of numerical simulation and the experimental results. In term of prestressed concrete girder, Kim et al. (2010) utilized PZT impedance signatures to locally identify

* 학생회원 • 부경대학교 해양공학과 석사과정 duyronan@gmail.com
** 정회원 • 부경대학교 해양공학과 박사후연구원
*** 학생회원 • 부경대학교 해양공학과 박사과정
**** 학생회원 • 부경대학교 해양공학과 박사과정
***** 정회원 • 부경대학교 해양공학과 교수 idis@pknu.ac.kr
****** 정회원 • 부경대학교 해양공학과 교수 wna@pknu.ac.kr

prestress tendon loss. It is found necessary to establish a finite element model for structural cables using impedance-based method.

The objective of this paper is to presents a finite element analysis on impedance parameters of anchor plates of structural cables under the change in cable forces. To achieve the objective, four approaches are implemented as follows: Firstly, theoretical background of electro-mechanical impedance is described. Secondly, anchor plates of structural cables are selected to experimentally examine the relationship between impedance parameters and cable force changes. Thirdly, finite element analysis is performed to verify the experimental results. Fourthly, a comparison between the experimental and numerical analysis on impedance parameters of anchor plate of structural cables under cable force changes is carried out.

2. Background of electro-mechanical impedance-based method

As shown in Fig. 1, the interaction between the piezoelectric patch and host structure is conceptually explained as an idealized 1-D electro-mechanical relation.

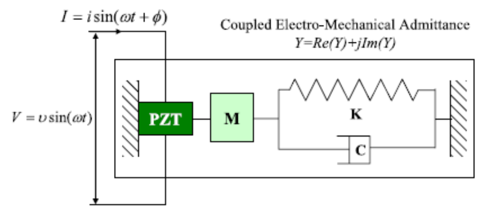


Fig.1. 1-D model electro-mechanical interaction between piezoelectric patch and host structure (Liang, 1994)

The electro-mechanical admittance Y(ω) (the inverse of electro-mechanical impedance Z(ω)) is generated as a combined function of mechanical impedance of host structure, $Z_s(\omega)$, and that of piezoelectric patch, $Z_a(\omega)$

$$Y(\omega) = i\omega\frac{wl}{t_c}\left[\left(\varepsilon_{33}^T - d_{3x}^2\,Y_{xx}^E\right) + \frac{Z_a(\omega)}{Z_a(\omega)+Z_s(\omega)}d_{3x}^2\,\widehat{Y_{xx}^E}\left(\frac{\tan kl}{kl}\right)\right] \tag{1}$$

In the equation (1), Y_{xx}^E is the Young's modulus of the PZT patch at zero electric field, ε_{33}^T is the dielectric constant, d_{3x} is the piezoelectric coupling constant in the x direction at zero stress, k is the wave number; w, l, and t_c are the width, length, and thickness of the piezoelectric transducer.

In this study, two indices, such as "frequency-shift index" and "root mean square deviation (RMSD)" are selected to quantify the change in impedance signatures:

$$f_{shift}(\%) = (f_I^* - f_I)/f_I \times 100 \tag{2}$$

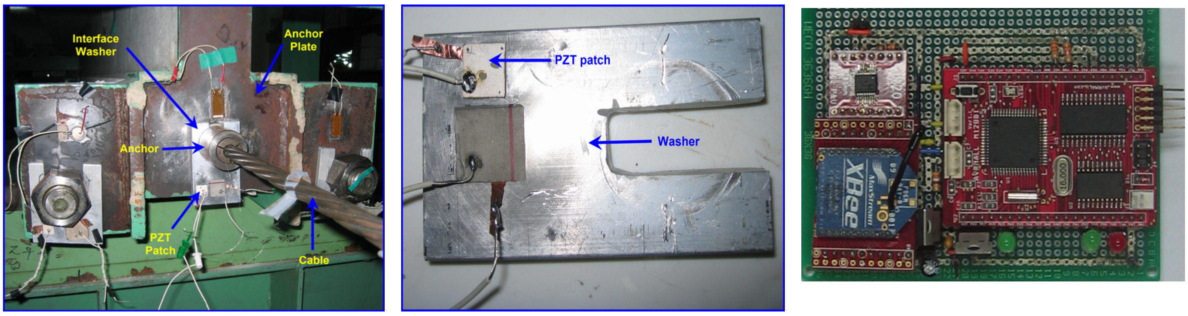
$$\mathrm{RMSD} = \sqrt{\sum_{\mathrm{i}=1}^{\mathrm{n}}\left[\mathrm{Re}(\mathrm{Z}^*(\omega_{\mathrm{i}}) - \mathrm{Re}(\mathrm{Z}(\omega_{\mathrm{i}})\right]^2 \Big/ \sum_{\mathrm{i}=1}^{\mathrm{n}}[\mathrm{Re}(\mathrm{Z}(\omega_{\mathrm{i}}))]^2} \tag{3}$$

Where f_I and f_I^* are the peak frequencies extracted from impedance signatures before and after damage occurrence, respectively. $Re(Z(\omega_i))$ and $Re(Z^*(\omega_i))$ are the real parts of the impedance at the *i*th frequency measured before and after damage occurrence, respectively.

3. Impedance parameters analysis for anchor plate

3.1. Experimental analysis on impedance parameters of cable anchor system

Fig.2 shows the schematic of lab-scale experiment test on impedances of cable anchor system. Fig.2(a) shows the cable anchor system, including cable, anchor plate, interface washer, anchor and PZT patch. Fig.2(b) shows the interface washer on which a PZT patch is surface-bonded. The cable is installed inside the concrete beam. The PZT patch is surface-bonded to the aluminum washer. Then, the aluminum washer is attached to the steel anchor plate. In this experiment, 6 cases of cable force which are ranged from 0.2ton to 8.1ton are carried out. The electro-mechanical impedance signatures are measured for each case of tension using Impedance Wireless sensor node (Imp-SSN)

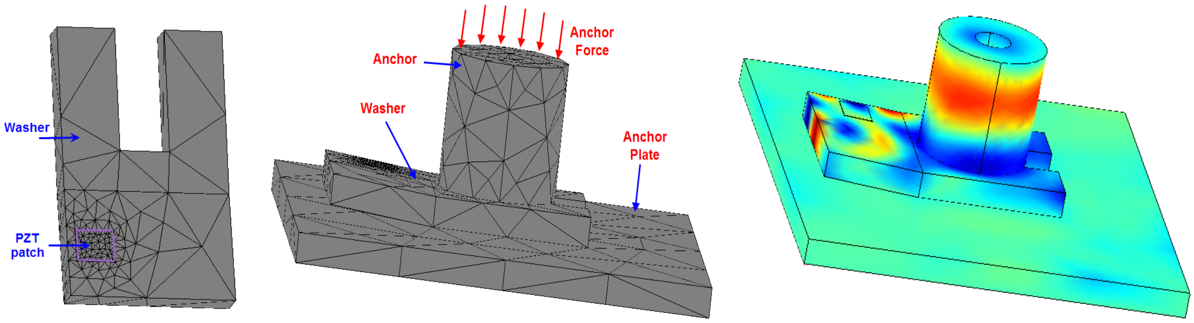


(a) Cable anchor system (b) Washer (c) Imp-SSN

Fig.2. Experiment test on impedance parameters of cable anchor system

3.2. Finite element analysis on impedance parameters of cable anchor system

A commercial software, COMSOL3.4, is used to model the anchor system and compute the electro-mechanical impedance generated from PZT patch. Fig.3 shows the finite element analysis on impedance parameters of cable anchor system. Fig.3(a), and (b) show the FE model of interface washer and cable anchor system, and fig. 3(c) shows the simulated impedance response.



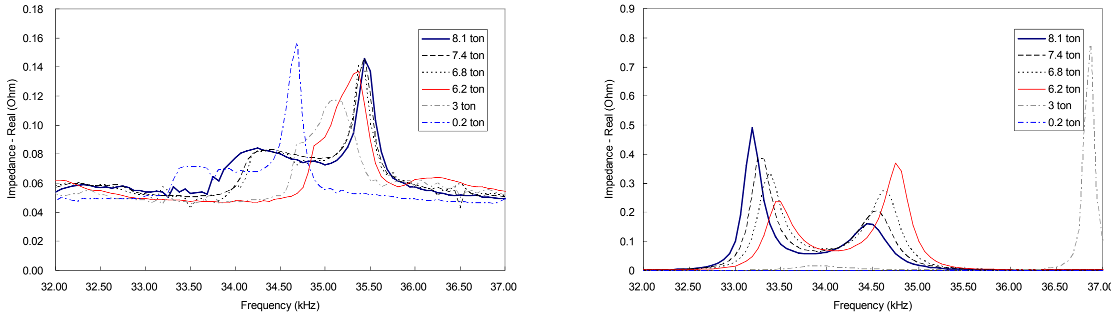
(a) Interface washer (b) Cable anchor system (c) Simulated impedance response

Fig.3. Finite element analysis on impedance parameters of cable anchor system

3.3. Results and discussion

Fig.4. show the impedance signatures measured from experiment and impedance signatures generated from finite element model. The impedance signatures for free washer is acceptably agreed between the experimental and numerical results. For simulated impedance signature, two peak frequencies are pointed, whereas there is only one peak frequency for experimental results. However, the higher peak frequency of numerical impedance response is not much different with that of experimental result.

Table 1. indicates the RMSD and frequency-shift index for various tensile forces. In both experiment and numerical model, the RMSD and frequency-shift index increase due to the decrease of tensile forces.



(a) Experimental results (b) Numerical results

Fig.4. Impedance signature for various cases of cable force

Table 1. RMSD index and frequency-shift index for various cases of tensile force

Load case	Tensile force (ton)	Relative loss (%)	RMSD		Frequency-shift index (%)	
			Experiment	FE model	Experiment	FE model
1	8.1	0.00	0	0	0	0
2	7.4	8.64	0.066	0.501	0	0.36
3	6.8	16.05	0.090	0.841	0.18	0.54
4	6.2	23.46	0.179	1.253	0.18	0.91
5	3	62.96	0.209	3.001	0.87	7.08
6	0.2	97.53	0.247	7.150	2.12	N/A

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