

Development of smart elastomeric bearing equipped with PVDF polymer film for monitoring vertical load through the support

Jongho Kim*, Yonkyu Park**, Inmook Choi** and Daeim Kang**

** Division of Physical Metrology, KRISS, P.O. Box 102, Yusong-Gu, Daejeon, 305-600, South Korea

*Tel. : +82-42-868-5241, fax : +82-42-868-5249, e-mail : jhk@kriss.re.kr

Abstract

This paper presents a smart elastomeric bearing using PVDF polymer film, which is very sensitive to dynamic loading condition. The PVDF polymer film is inserted into the elastomeric bearing to monitor the normal load, which is applied to the bridge structure. Therefore, the prototype of the smart elastomeric bearing is finally fabricated with the electric circuit for signal of the PVDF polymer film subjected to vertical loading. The evaluation system for smart elastomeric bearing is manufactured with shake, accelerometer and plate. The bearing was tested under sinusoidal loading condition. Finally the system confirmed that real time measurement of elastomeric bearing reaction provides the structure with certain intelligence.

1. Introduction

The durability of bridges and the ability to maintain their initial structural capacity are topic of interest[1, 2]. For a long time, inspection programs have been carried out to follow up a changing state of large structure. To help managers in their decisions, an advanced metrology was introduced in sensitive parts of bridges to assess their structural aptitude. In particular, an abnormal behavior of the structure often causes a load re-distribution on its supporting parts. Thus if the reaction force is monitored at supporting parts, the entire structure can be assessed and its main deficiencies eventually detected.

Generally a bridge is composed of connections of some plates, and a pier supports the decks. Meanwhile an elastomeric bearing used in between deck and pier provides a flexibility of bridge against forces caused by earthquake or passage of vehicle on the bridge. Thus the elastomeric bearing makes it possible to act as

an isolation bearing to reduce the damaging motion that horizontal earthquakes transmit to bridge. The isolation bearing consists of thin sheets of rubber bonded to interleaving steel plates, thus, providing sufficient vertical rigidity to sustain gravitational loading and yet allowing horizontal flexibility to shift the fundamental frequency of the isolated bridge away from the dominant frequency range of most earthquake.

Meanwhile there are some techniques for diagnosis of bridge structure using strain gages or optical fibers[3, 4] attached to bridge structure. However these methods are inconvenient and inefficient since many sensors are needed and attached to bridge structure. On the other hand, if a PVDF film sensor is inserted into elastomeric bearing, the integrity of bridge structure can be easily and effectively monitored and evaluated. The properties of PVDF film are as follows[5]: wide frequency range(0.001

Hz to 10^9 Hz; vast dynamic range; low acoustic impedance; high voltage output; high stability on environmental condition (moisture, chemical and so on); glue with commercial adhesives. Thus, this paper describes a development of smart elastomeric bearing using PVDF polymer film to monitor the safety of bridge structure effectively and simply.

2. Theoretical approach for bridge modal analysis

Let us assume a bridge as a beam with support restraint conditions at its ends. If such restraints against either translations or rotations are linearly elastic, they may be idealized as springs, as shown in Figure 1. Let the symbol k_1 and k_2 represent the stiffness constants for the translation springs at the ends.

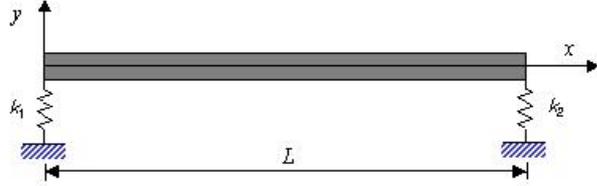


Figure 1. Simple beam model with spring constant for bridge modal analysis.

If the spring constants are same as k , the governing equation and the boundary conditions may be expressed as

$$\frac{\partial^2}{\partial x^2} \left(EI \frac{\partial^2 Y}{\partial x^2} \right) dx = -m \frac{\partial^2 Y}{\partial t^2} \quad (1)$$

$$EI(Y''')_{x=0} = -k(Y)_{x=0}, \quad (2)$$

$$EI(Y'')_{x=0} = 0, \quad (3)$$

$$EI(Y''')_{x=L} = -k(Y)_{x=L}, \quad (4)$$

$$EI(Y'')_{x=L} = 0, \quad (5)$$

where m is a mass per unit length, E is an elastic modulus and I is an area moment of inertia, and Y is the displacement in the direction y -axis. Thus the normal functions of governing equation (1) can be expressed as

$$Y(x) = A(\sin \beta x + C_2 \cos \beta x + C_3 \sinh \beta x + C_4 \cosh \beta x) \quad (6)$$

Using equations (2) to (5), the solution of characteristic equation β can be obtained by

$$\frac{E^2 I^2}{L^6} (\beta L)^6 (1 - \cos \beta L \cosh \beta L) - 4k^2 \sin \beta L \sinh \beta L = 0 \quad (7)$$

and the variables can also be calculated by

$$C_2 = \frac{1}{\cos \beta L - \cosh \beta L} (C_3 \sinh \beta L - \sin \beta L), \quad (8)$$

$$C_3 = \frac{EI\beta^3 \cos \beta L - EI\beta^3 \cosh \beta L + 2k \sin \beta L}{EI\beta^3 \cos \beta L - EI\beta^3 \cosh \beta L + 2k \sinh \beta L} \quad (9)$$

$$C_4 = C_2, \quad (10)$$

The reaction forces at ends of beam are represented by

$$F_{x=0} = AEI\beta^3 (-1 + C_3), \quad (11)$$

$$F_{x=L} = AEI\beta^3 (-\cos \beta L + C_2 \sin \beta L + C_3 \cosh \beta L + C_4 \sinh \beta L) \quad (12)$$

Meanwhile, if we know the natural frequency, f , the β can be calculated easily by

$$\beta = \sqrt[4]{\frac{4\pi^2 f^2 m}{EI}} \quad (13)$$

2. Dynamic behavior of smart elastomeric bearing using PVDF film

Figure 1 shows the spring constants k_1 , k_2 , which are assumed as the spring constant s of two elastomeric bearing with PVDF film. Therefore the dynamic behavior of the elastomeric bearing should be evaluated. In order to monitor the dynamic behavior of elastomeric bearing supporting a bridge, a PVDF film was inserted into the elastomeric bearing as shown in Figure 2

(a). The PVDF film was attached to the elastomeric bearing and covered by adhesive layer using epoxy. Figure 2 (b) shows the smart elastomeric bearing with PVDF film.

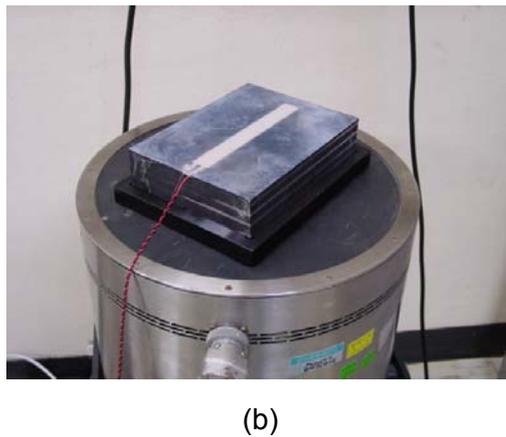
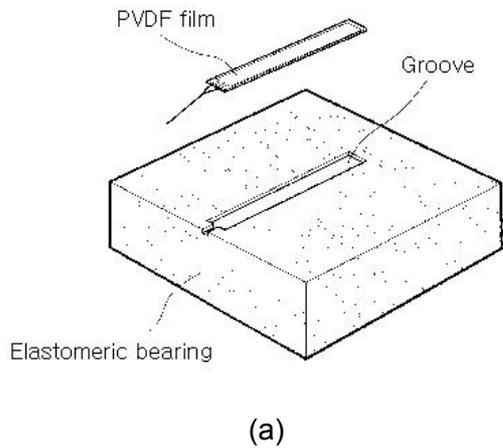


Figure 2. Elastomeric bearing on exciter : (a) schematic diagram of with PVDF film on the elastomeric bearing; (b) Fabrication of elastomeric bearing with PVDF film.

Figure 3 represents an experimental set up for measuring a dynamic behavior of elastomeric bearing. The dynamic force was obtained by accelerometer sensor attached to 15 kg mass, which was put on the elastomeric bearing with PVDF film. The bearing was accelerated by shaker (B & K 4802 and 4817), and the signal amplifier(B & K 2708). From since sweep method using FFT analyzer and actuator, the sensitivity of force (N) to output voltage of PVDF film was obtained as

shown in Figure 4. The sensitivity was flat in range 40 Hz to 100 Hz. The resonance frequency of elastomeric bearing, caused by interaction of spring of elastomeric bearing and mass 15 kg, was occurred at about 32 Hz.



Figure 3. Experimental set up for dynamic behavior of elastomeric bearing with PVDF film.

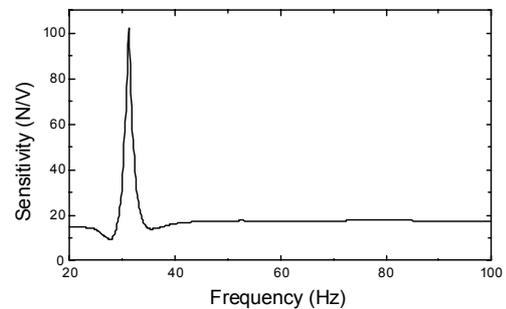


Figure 4. Sensitivity of force (N) to output voltage of PVDF film as a function of frequency.

3. Procedure for monitoring safety of bridge structure using smart elastomeric bearing with PVDF film

The smart elastomeric bearing was developed to monitor the safety of bridge structure, and Figure 5 represents the procedure for safety evaluation of the bridge structure using the modal analysis [6] obtained from PVDF film, which was inserted to elastomeric bearing.

First, we can measure the dynamic reaction forces of Equations (11) and (12) from PVDF film sensor inserted into elastomeric bearing supporting a bridge. Next, using signal obtained from the smart elastomeric bearing, the frequency analysis is performed by FFT analyzer. After modal analysis is performed by boundary conditions of bridge structure as shown in Figure 1 and the obtained frequency analysis, the summation of the calculated modes like Equation (1) is conducted. In reference, if we obtain the natural frequency, f , from signal analysis, we can calculate the solution of characteristic equation β . On the other hand, we can estimate the damage of bridge structure from the change of natural frequency in case of the bridge being damaged.

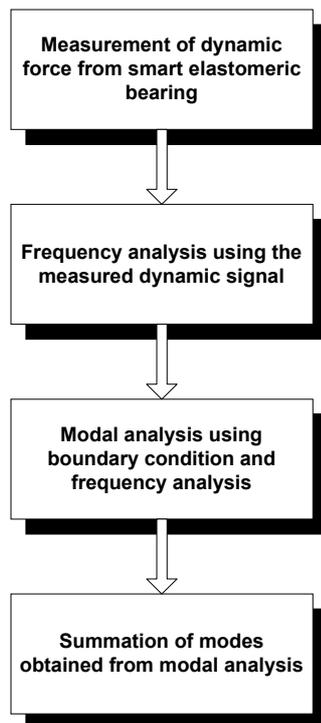


Figure 5. Procedure for safety evaluation of bridge structure using smart elastomeric bearing

In the future, more study on the analysis of bridge structure as shown in Figure 6 and experimental evaluation, in case of passage of vehicle on the bridge or earthquake, are needed to realize the use of the smart

elastomeric bearing.

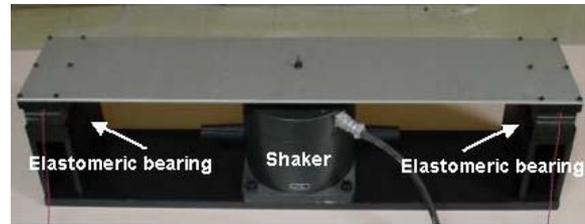


Figure 6. Schematic diagram of bridge structure equipped with smart elastomeric bearing using PVDF film sensor.

4. Conclusion

The smart elastomeric bearing with PVDF film sensor was developed in order to monitor and evaluate the integrity of bridge structure. The PVDF film was inserted into elastomeric bearing and covered by protection layer. The dynamic behavior of the smart elastomeric bearing was evaluated by an arbitrary mass and shaker. Thus the smart elastomeric bearing showed the possibility of intelligence sensor for real time monitoring the dynamic behavior of the bridge structure.

Acknowledgement

This work has been supported by the National Research Laboratory for the Force Measurement & Evaluation (Project No. 2000-N-NL-01-C-141).

Reference

1. Lin C.C., Soong, T.T. and Natke, H.G. "Real -time system identification of degrading structures," J Engrg. Mech. ASCE, Vol. 126, No. 10, pp.126-136, 1990.
2. Sanayei, M. and Onipede, O. "Damage assessment of structures using static test data," AIAA J Vol. 26 No. 1, pp. 104-110, 1991.
3. Miessler, H.J. and Lessing, R. "Monitoring of load bearing structures with optical fibres," IABSE Symposium, Lisbon, 1989.

4. Caussignac, J.M. Barbachi, M. and Chabert, A. "Bridge bearings equipped with optical fiber sensor for measuring vertical load through the support," Proceeding of SPIE, Vo. 2719, pp. 220-228, 1996.
5. Piezo film sensors technical manual, Measurement Specialties, Inc., www.msisua.com.
6. Hajela, R and Soeiro, F.I. "Structural damage detection based on static and modal analysis," AIAA J. Vol 28, No. 6, pp. 1110-1115, 1990.

Contact person for paper

Dr. Jongho Kim
Division of Physical Metrology, KRISS, P.O.
Box 102, Yusong-Gu, Daejeon, 305-600,
South Korea

Tel. : +82-42-868-5241

Fax : +82-42-868-5249

e-mail : jhk@kriss.re.kr