A Correlation Analysis regarding the Temperature Effect for a Suspension Bridge

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ABSTRACT: The monitoring for measuring structural behavior has been advanced. Recently, many researchers have studied on the structural health monitoring using the GNSS (Global Navigation Satellite System). This paper presents temperature behavior for a Gwang-An bridge which is three span suspension bridge in Korea. The behavior of a middle span have analyzed on ambient temperature change. As the time passed from January to June in 2013, the vertical displacement was decreased and the temperature was increased more and more at the middle span. And the correlation analysis was performed between the temperature and the vertical displacement using the thermometer and GNSS. Also monthly changes of the temperature and natural frequency had been measured. And then the correlation analysis was performed between the temperature and natural frequency. As a result of the evaluation regarding thermal effect at the middle span, relationship between the temperature and natural frequency seemed to have trend of inverse proportion.

Keywords: Suspension bridge, GNSS, Dynamic characteristics, Temperature effect, Correlation analysis

1 INTRODUCTION

Computerized maintenance and management system have installed for systematic control and safety assessment in cable stayed bridges and suspension bridges that have been completed recently. Previous studies assumed that the temperature effect was meager or nothing and not reflected to structural analysis due to difficulty of mathematical formularization in the dynamic characteristics estimation of structures. However, changes of dynamic characteristics according to the temperature was occurred in bridges which have exposed in the severe temperature environments. And some study described that these characteristics changes might be stronger than changes due to structural damage[1]. For the purpose of quantitative evaluation of uncertainty factors and reliable analysis of dynamic behavior for the bridge, the Gwang-An bridge has been accumulating data about dynamic characteristics by measuring ambient vibration for a long time. There are many previous studies focusing on the dynamic behavior characteristics of bridges using ambient vibration. However there have been performed these studies at the initial safety inspection or precision safety diagnosis after bridge completion. Therefore it was rare that long-term dynamic behavior change of the structure was monitored and analyzed through the real-time measurement. In this paper, possibility of the dynamic characteristics change was evaluated based on accumulated measurement data from January to June in 2013.

2 BRIDGE MEASUREMENT

2.1 The Gwang-An bridge

Gwang-An bridge was constructed in 2002 and Busan Infrastructure Corporation has been maintaining in Korea. This bridge is three-span, two-hinge stiffened, earth-anchored suspension bridge with a total length of 900m (200m + 500m + 200m).

Fig. 1 An overview of the Gwang-An bridge

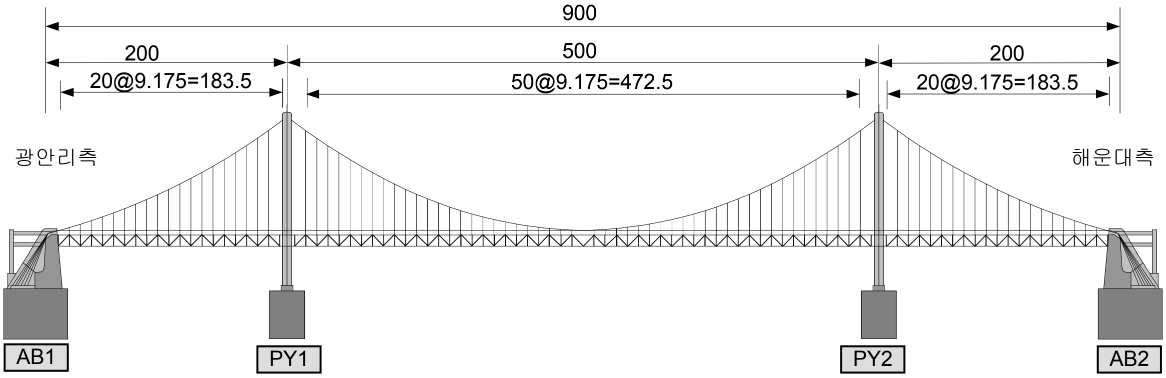

Fig. 2 A front view

2.2 Bridge measurement system

The Gwang-An bridge measurement system monitors and analyzes the status of the bridge by receiving signals from sensors that were installed at some parts of the bridge in real-time. 9 types of sensors such as accelerometer, seismometer, thermometer, laser displacement meter and GNSS were installed in the suspension bridge. Static signals such as temperature are accumulated 1 time per 10 minutes and dynamic signals such as vibration are accumulated 100 times per second. Accelerometers that can measure vertical vibration signals were installed at up and down line of the girder. Accelerometers are force-balance type for low-frequency range with the dynamic range of 140dB and bandwidth of accelerometers is from DC to 200Hz. Two GNSS were installed for measuring displacement at up and down line of the middle span, and GNSS perform monitoring by receiving data in real-time.

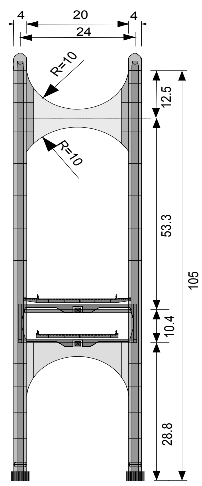

Fig. 3 A cross section of the pylon

3 ANALYSIS RESULTS

3.1 Results of long-term measurements

Figure 4 is changes of temperature and figure 5 is changes of vertical displacement at the middle span. Where GNSS_MSL indicates the landward GNSS in the middle span, GNSS_MSS indicates the seaward GNSS in the middle span and THG1 is the thermometer in the middle span. As a result of analysis for measurement data from January to June in 2013, maximum temperature was 26.0˚C, minimum temperature was -2.8˚C, maximum vertical displacement at the middle span was 46.1mm and minimum was -353.7mm, when reference point was measurement data in January 1st, 2013. Measurement data from GNSS are 10Hz, and data in figure 5 is average value during an one-day. As the time passed from January to June, temperature was increased and vertical displacement was decreased more and more at the middle span. That was why stiffness of the middle span became small according as the temperature increased.

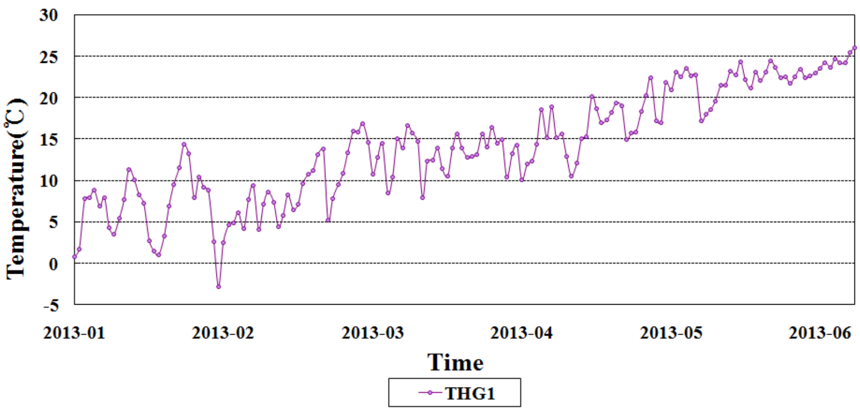

Fig. 4 Changes of temperature at the middle span

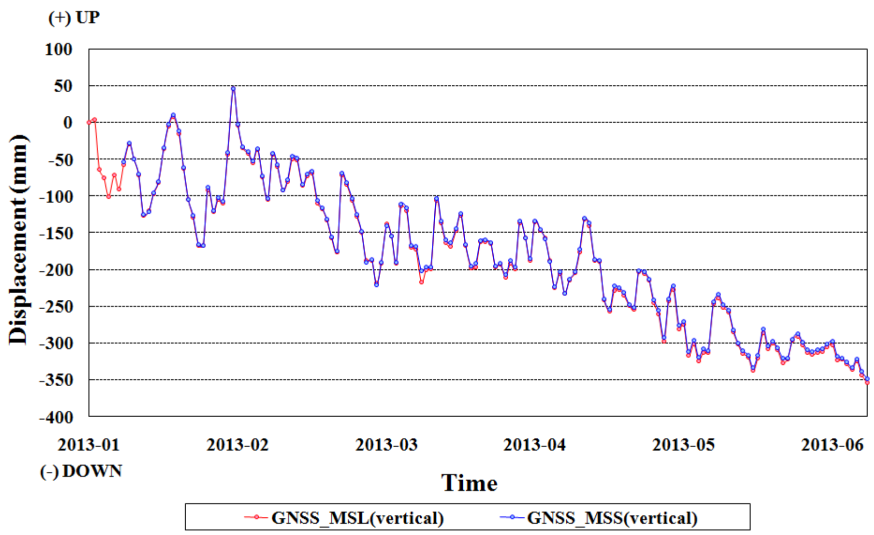

Fig. 5 Changes of vertical displacement at the middle span

Correlation analysis was performed for the purpose of grasping correlation between the temperature and vertical displacement at the middle span. As a result, large negative correlation coefficient(R) of 0.9941 and 0.9940 were shown in the figure 6.

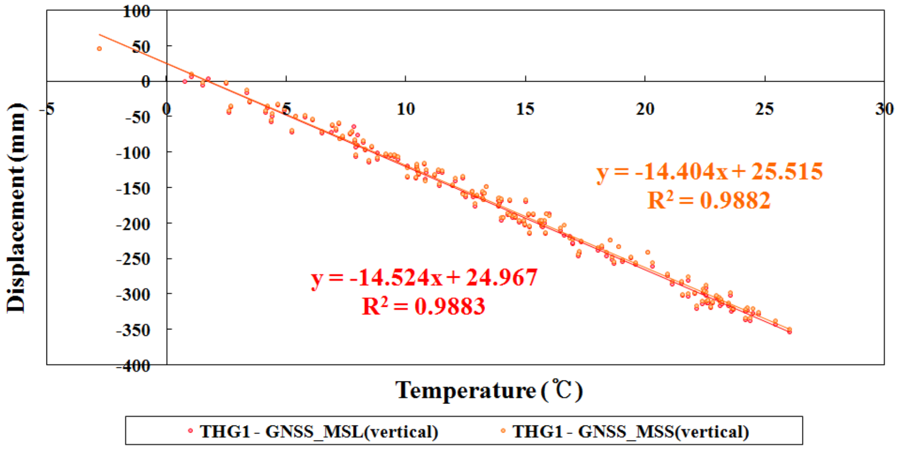

Fig. 6 Correlation analysis results between the temperature and displacement

3.2 FFT Analysis

Dynamic characteristics of the Gwang-An bridge was analyzed using GNSS and accelerometers that were installed in the girder. GNSS data have been measured at the frequency 10Hz. Also a modal frequency response was analyzed using FFT (Fast Fourier Transform) analysis. The GNSS data was transformed into the acceleration data by double-differentiating with respect to time. In case of bending vibration, FFT analysis was performed by extracting signals with respect to bending vibration after signals with respect to torsional vibration was eliminated by adding acceleration of point a and b as shown in the figure 7.

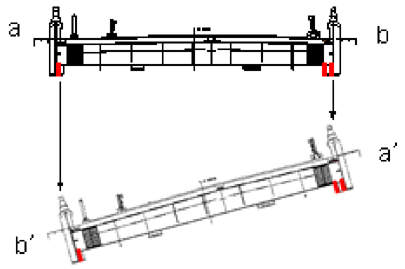

Fig. 7 An example girder for the acceleration analysis

Figure 8 is the acceleration data stream which collected from accelerometer and figure 9 is the result of the FFT analysis using acceleration data. Figure 10 is the displacement data of the GNSS. And the acceleration data of the time-domain is deduced by double-differentiating GNSS displacement data as shown in the figure 11. When the FFT analysis is performed using the acceleration data of the time-domain, the acceleration data of the frequency-domain can be deduced as shown in the figure 12.

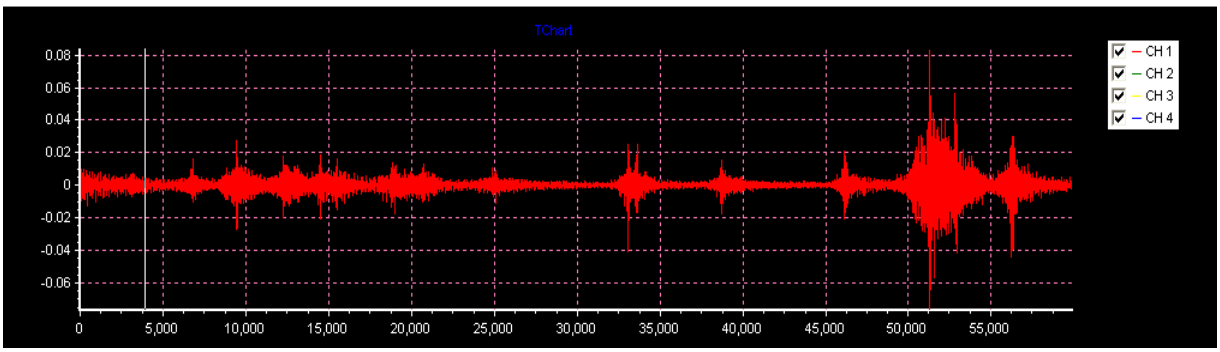

Fig. 8 The acceleration data stream collected from accelerometer

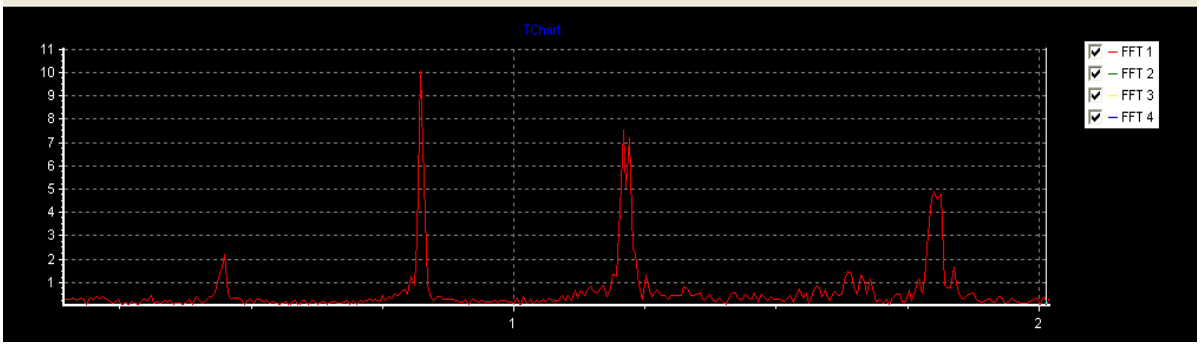

Fig. 9 The result of the FFT analysis using acceleration data

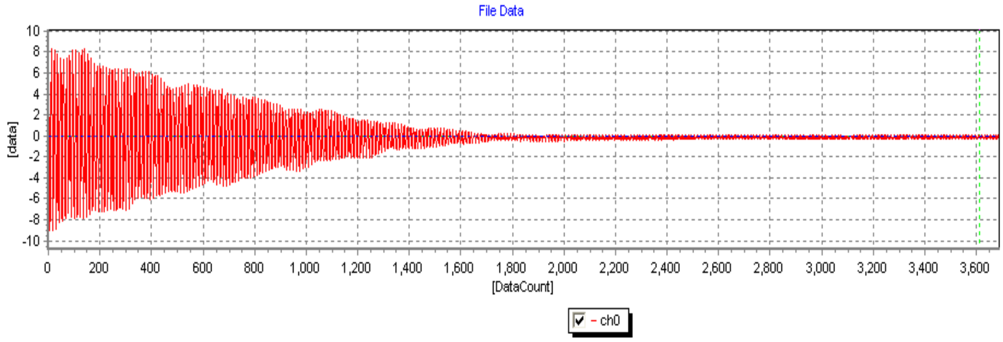

Fig. 10 The displacement data of the GNSS

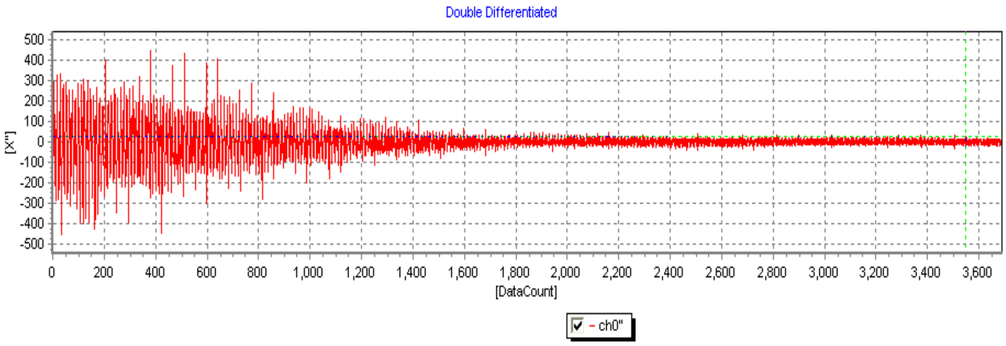

Fig. 11 The acceleration data deduced by double-differentiating GNSS displacement data

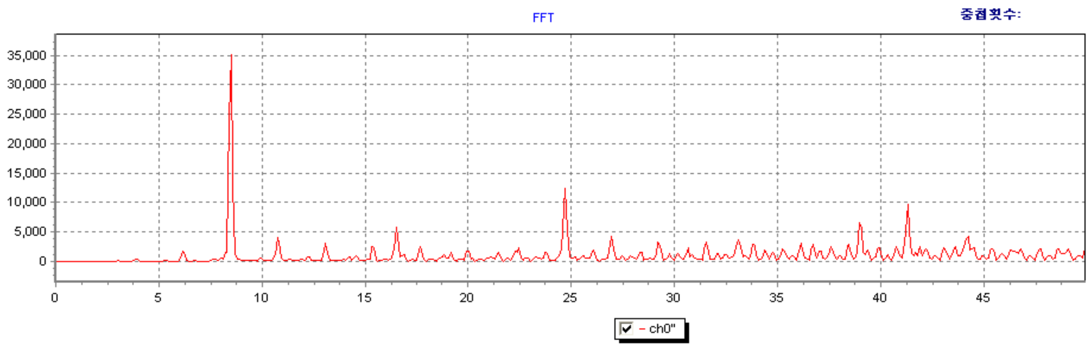

Fig. 12 The result of the FFT analysis using GNSS data

3.3 The results of dynamic characteristics analysis using the GNSS and accelerometer

Vertical displacement factor by the ambient vehicle loading is dominant in GNSS signals that was measured from the suspension bridge because GNSS signals is displacement value of the corresponding measuring point with respect to time. Besides various error and noise factor is contained in GNSS signals. For reducing these effects in GNSS signals of the Gwang-An bridge, signals of the only interested range between from 0.1 to 1.0Hz were separated by using band pass filter.

Also GNSS displacement data was transformed by double-differentiating the acceleration data so dynamic characteristics extraction was performed effectively. Table 1 is the FFT results that are monthly analysis results of the bending vibration based on data which was deduced from GNSS and accelerometer.

Table 1 Monthly analysis results of the bending vibration

Bending vibration		Middle span	
		GNSS	Accelerometer
2013.01.	1st	0.2610	0.2598
	2nd	0.2840	0.2837
	3rd	0.4634	0.4642
2013.02.	1st	0.2605	0.2605
	2nd	0.2831	0.2830
	3rd	0.4612	0.4633
2013.03.	1st	0.2591	0.2601
	2nd	0.2825	0.2822
	3rd	0.4610	0.4621
2013.04.	1st	0.2561	0.2592
	2nd	0.2821	0.2815
	3rd	0.4605	0.4610
2013.05.	1st	0.2552	0.2582
	2nd	0.2818	0.2810
	3rd	0.4597	0.4603
2013.06.	1st	0.2547	0.2573
	2nd	0.2811	0.2806
	3rd	0.4601	0.4598

Natural frequency measurement results of GNSS and accelerometer signals were compared in the same time. Natural frequency extraction was performed correctly in that these data were very similar. Therefore, if proper filtering and double-differentiating technique are applied to measured GNSS signals, it is possible to extract numerous natural frequency. And it means that GNSS can replace accelerometer of corresponding points.

3.4 Correlation analysis between temperature and natural frequency

As the time passed from January to June in 2013, natural frequency was decreased as seen in the table 1. In other words, relationship between the temperature and natural frequency seemed to have trend of inverse proportion. And then the correlation analysis was performed between the temperature and natural frequency. As a result of the evaluation regarding thermal effect at the middle span, the temperature and natural frequency had a large negative correlation coefficient(R).

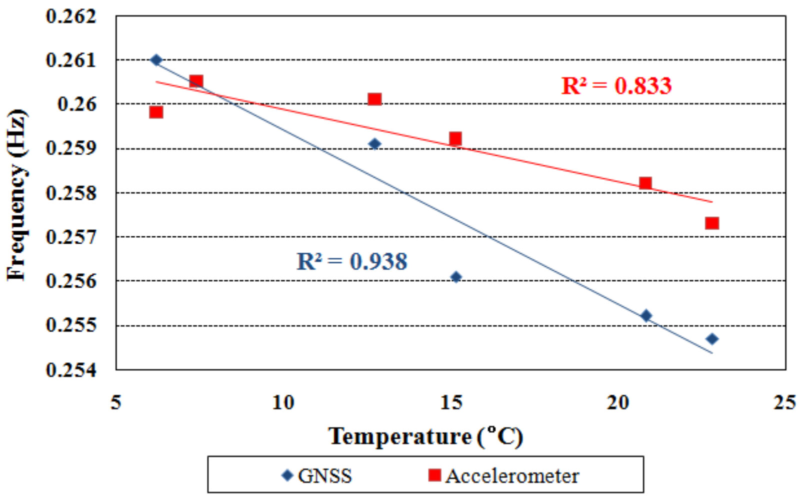

Fig. 13 The result of correlation analysis between temperature and natural frequency

4 CONCLUSIONS

This paper presents that vertical displacement behavior of the girder and dynamic characteristics analysis was performed for the Gwang-An bridge in Korea. As the time passed from January to June in 2013, temperature had been increased from -2.8˚C to 26 ˚C and vertical displacement had been decreased from 46.1mm to -353.7mm at the middle span. Also the natural frequency at the middle span seemed to have decreasing trend. That was why stiffness of the middle span became small according as the temperature increased. Therefore temperature effect should be considered in case of reflecting dynamic characteristics such as vibration test, analysis model design and state valuation of the suspension bridge.

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