서해대교 현장계측에 기반한 풍속스펙트럼 모형의 비교연구

A Comparative Study of Wind Speed Spectrum based on the In-Situ Observation at the SeoHae Bridge Site

김상범† ·이성진*

Saang Bum Kim, Sang-Sub Ahn and Sung Jin Lee

Key Words : Wind Spectrum (윈드 스펙트럼), In-Situ Observation (현장계측), Turbulence Intensity (난류강도).

ABSTRACT

A comparative study of wind speed spectrum based on the in-situ observation at the SeoHae bridge site is conducted. Wind speed and directions of the SeoHae bridge site is measured and analyzed. Mean wind speed and turbulence intensity are estimated. The power spectral density function of the fluctuating component of the wind velocity is estimated. Several wind spectrum models of gust wind turbulence are compared and discussed based on the estimated wind spectrum.

1. Introduction

Advancement of structural engineering and development of new construction materials have brought a lot of construction of long span bridges, which connect two regions located far away and make a transportation route. However, these long span bridges like suspension bridges and cable stayed bridges are very susceptible to vibration, because of their light weight, high stiffness, and slender shape. The most common vibration of long span bridges is the wind-induced vibration, such as vortex shedding, galloping, flutter, buffeting, etc. Long span bridges have low natural frequencies that make them susceptible to respond to the spectral contents of the wind and make the bridge unstable(2). Wind loads become the most important factors for the design and construction of the bridge, as the span length of the bridge increase. So wind induced vibrations should be accounted for design and construction of bridges. To evaluate the wind resistance characteristics of the long-span bridge, buffeting analysis is conducted using the design wind speed spectrum of the bridge site. There are several models for the wind speed spectrum. Since, each wind speed spectrum model has unique characteristics and these characteristics are highly influenced by the meteorological and geographical environments of the specific sites, proper use of the wind speed spectrum model for that site is very important for the safe and economic design of the bridge. The Korea Highway Corporation operates a monitoring center for the SeoHae Bridge, which connects PyoungTaek and DangJin. The monitoring center is located in HaengDam island beside the Yellow Sea. The SeoHae cable stayed bridge has a main span of 470 m and the design wind speed (10 min mean, 10 m above the ground, 100 year return period) is 35 m/s(1). The monitoring center of the SeoHae Bridge is measuring the wind speed and directions with 100 Hz and the corresponding accelerations of the cables. In this paper, measured wind velocities are analyzed. Mean wind speed and turbulence intensity are estimated. The power spectral density function of the fluctuating component of the wind velocity is estimated. Several wind spectrum models are compared and discussed based on the estimated wind spectrum.

2. Measurement

Figure 1 show the SeoHae cable stayed bridge and the sensor locations where the anemometers are placed. The terrain surrounding the bridge site is a combination of open water, flat suburban and hilly terrain. Two anemometers are installed at the top of a bridge pylon (vw00 & vw01), one is at the middle of the main span (vw10), and last one is on the approach bridge (vw21). Two types of the anemometers are used for the in-situ observation. One is an ultra sonic type and the other is a propeller type. Ultra sonic anemometers generate wind speed data for each of 3 wind directions: North, West and Upward. Each wind direction means the direction which the wind blows from. Propeller type anemometers generate wind velocity data with the magnitude and the direction which is the clock wised angle from the North direction. Anemometer locations are summarized in Table 1.

The wind velocity data were recorded at April 6, 2006. The data were taken 4 times at a sampling rate of 100 Hz for around 30 min. Figure 2 shows the wind direction at each measurement. Wind velocities from 11:19 AM and 12:40 PM have two clearly distinct directions, while wind velocities from 14:06 PM and 15:35 PM have almost one direction (Figure 3). Figure 4 shows the time

† Kim, Saang Bum; Samsung E&C
E-mail : saangkim@gmail.com
Tel : (010) 7196-0386, Fax : (02) 2145-6477
* Samsung E&C

history of the magnitude of the wind velocity measured from 15:35 PM and estimated 10 min mean wind velocity and variations of $\sigma_{u[i]}$.

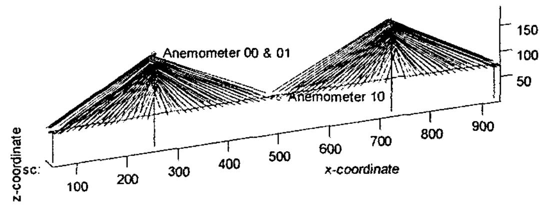
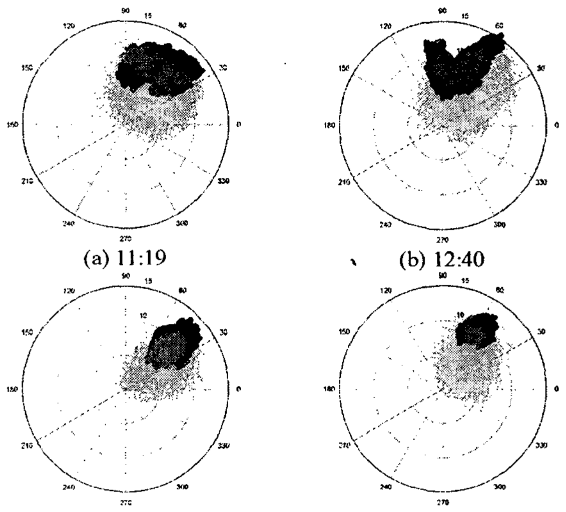


Figure 1 SeoHae Bridge and Sensor Locations

Table 1 Anemometer Configurations

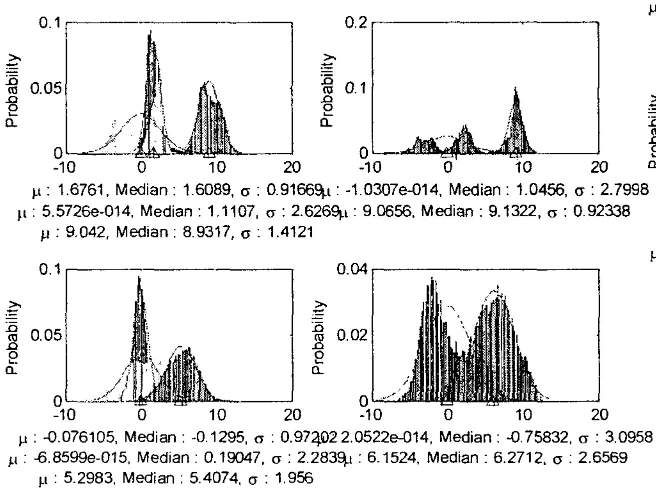
Sensor	Locations	Longitudinal Distance (m)	Height (m)	Type
vw00	CSB Pylon	260	185.393	Ultra
vw01	CSB Pylon	260	185.393	Propeller
vw10	CSB Deck	495	62	Ultra
vw21	FCM Deck	2102.5	57.004	Propeller



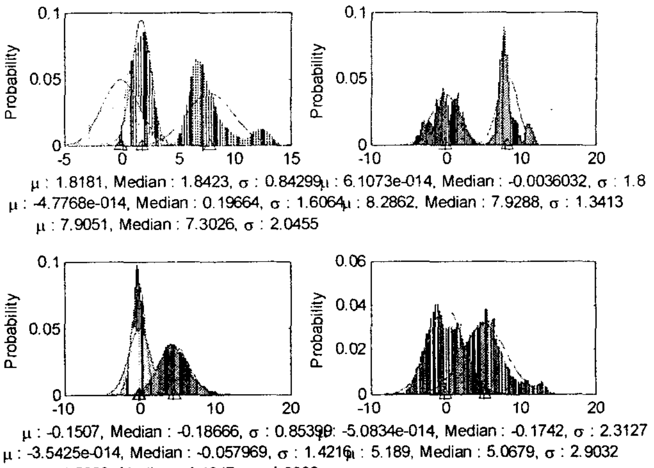
(a) 11:19 (b) 12:40

(c) 14:06 (d) 15:35

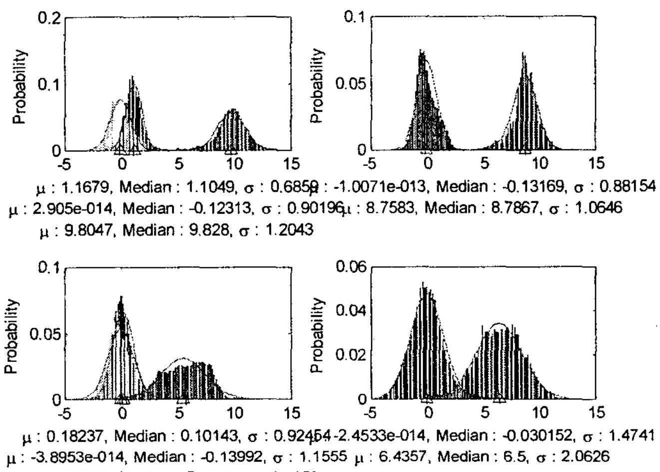
Figure 2 Direction of Wind Velocity



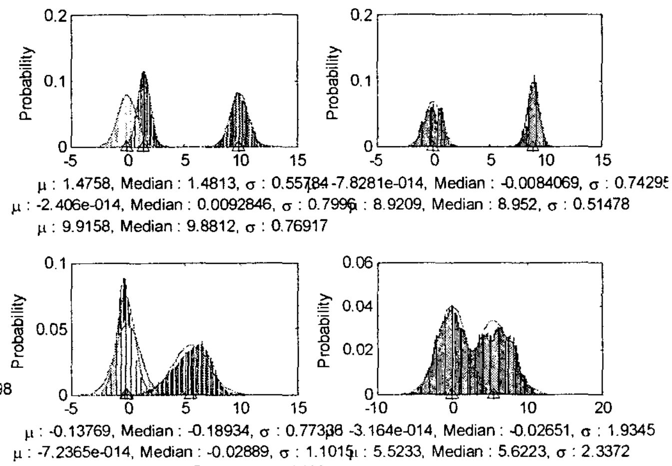
(a) 11:19 AM



(b) 12:40 PM

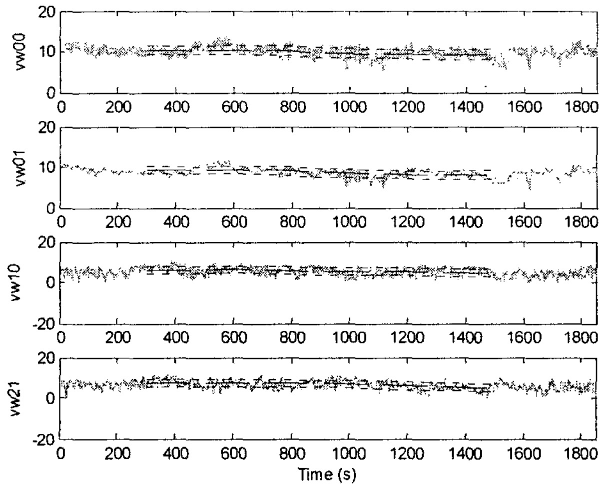


(c) 14:06 PM

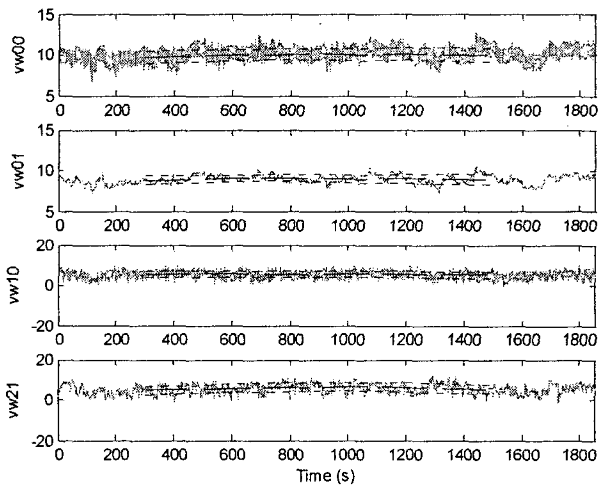


(d) 15:35

Figure 3 Histogram of Measured Wind Velocity

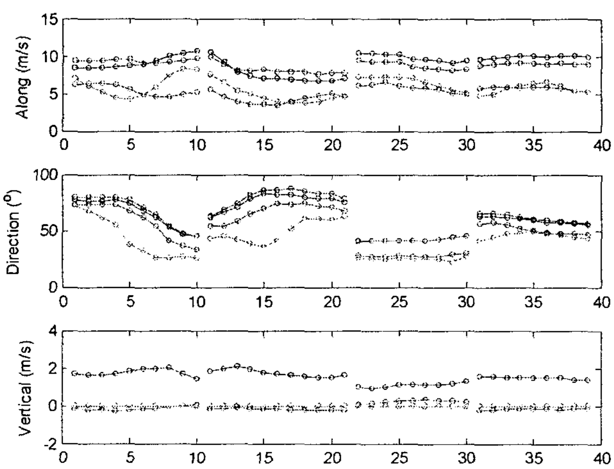


(a) 14:06 PM

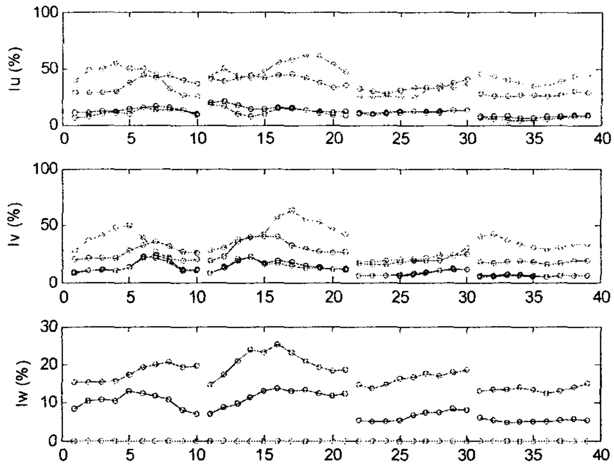


(b) 15:35 PM

Figure 4 Time History of Measured Wind Velocity



(a) 10 min mean Wind Speed and Direction



(b) Turbulence Intensity

Figure 5 Estimated Turbulence Characteristics

Table 2 shows the estimated turbulence intensity. Turbulence intensity at the top of the pylon (260 m) is smaller than the intensity at the deck (62 m) as 33.71 %, 44.34 %, 48.56 % for each of along wind, across wind, and vertical directions.

Table 2 Turbulence Intensity (%)

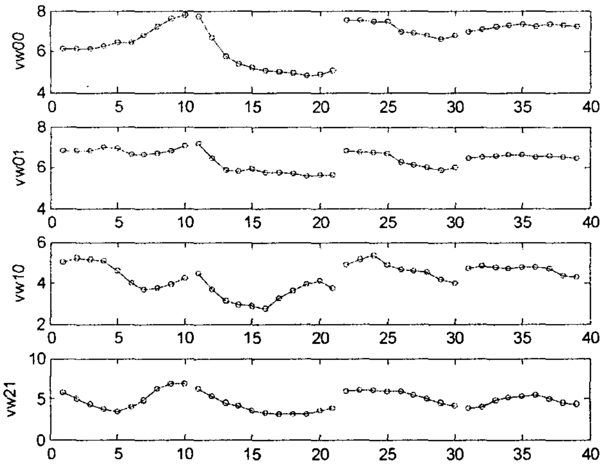
	Iu	Iv	Iw		Iu	Iv	Iw
vw00	12.774	13.899	10.314	vw10	35.669	26.373	17.806
	14.631	15.316	11.459		40.025	30.767	20.463
	11.312	8.0024	6.5884		32.725	19.242	16.351
	7.3607	5.9646	5.3993		26.389	17.926	13.49
vw01	10.564	14.349		vw21	41.824	32.996	
	11.54	14.562			50.613	45.205	
	10.806	8.6588			28.632	21.676	
	5.4019	5.5765			39.979	34.366	

The variation of mean wind speed, $u_\mu[z]$ with height z can be represented by a logarithmic relationship

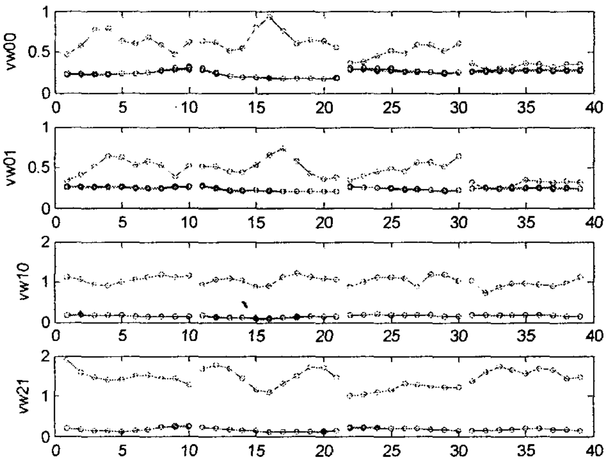
$$u_\mu[z] = \frac{u_*}{k} \ln\left[\frac{z - z_d}{z_0}\right] \qquad (1)$$

where u_* is the friction velocity (shear velocity), z_0 is the roughness length of the surface, z_d is the zero-plane displacement and k is the von Kármán's constant (k=0.4).

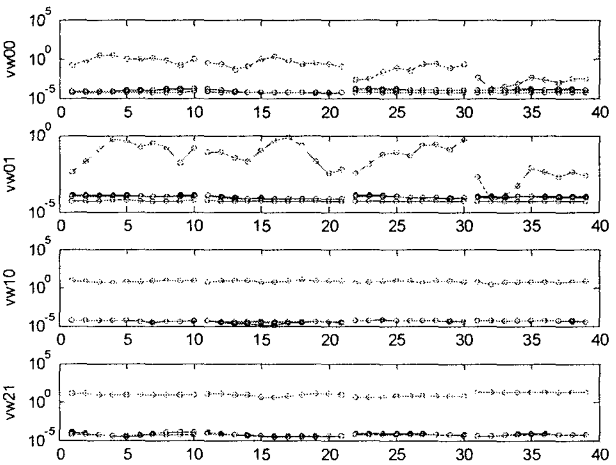
Roughness length is estimated as 5e-5 m through the surface drag coefficient, and 0.09 through the Kaimal wind speed spectrum (Figure 6). Corresponding friction velocities are 0.214 m/s and 0.33 m/s for each.



(a) $u_{\mu}[10]$ (m)



(b) Friction Velocity (m/s)

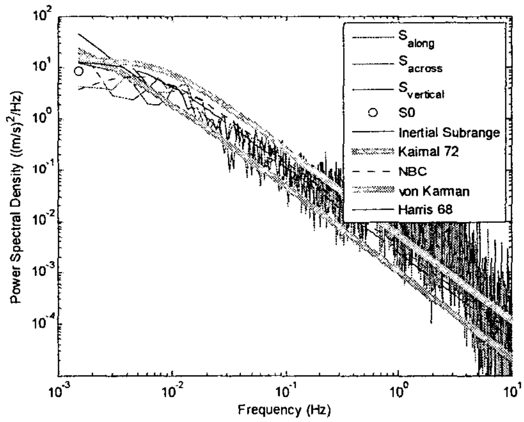


(c) Roughness Length (m)

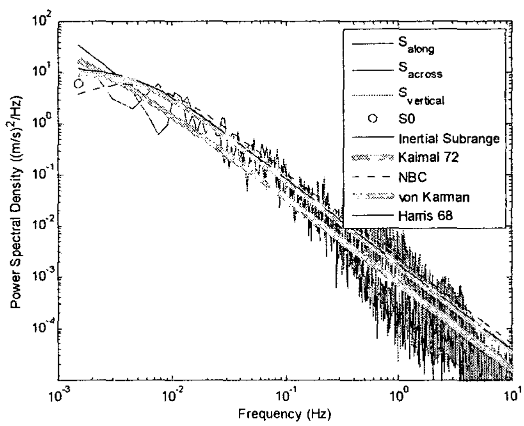
Figure 6 Variations of 10 min Mean Characteristics

3. Wind Speed Spectrum

Figure 7 shows that the resonance arises around 1-3 Hz. Usually 100 Hz sampling of the anemometers is too high, and the high frequency resonance components need to be ignored. The von Kármán spectrum usually gives over estimated results at high frequency range. Many literatures suggest that the von Kármán spectrum should be used for the very low frequency structures, such as offshore structures, which have motions with periods or about 50 to 120 s. One other problem with Kármán spectrum is that this spectrum requires the information on the length scale, which is not obtained easily from the measurement. Kaimal spectrum shows a good agreement with the experimentally obtained wind spectrum, if the resonance range is ignored, but for the very low frequency range below 0.003 Hz, where the Kármán spectrum shows a good agreement. Since most of the long span bridges have natural frequencies larger than 0.01 Hz, it is recommended to use the Kaimal spectrum for the wind resistance design for bridges.



(a) vw00 (CSB Pylon 185.393 m, Ultra Sonic)



(b) vw01 (CSB Pylon 185.393 m, Propeller)

Figure 7 Wind Speed Spectrum

4. CONCLUSIONS

Wind speed and directions of the SeoHae bridge site is measured and analyzed. Experimentally obtained wind spectrum is compared with the several wind spectrum models: Kármán spectrum, Kaimal Spectrum and Davenport Spectrum. For the most of the cases, Kaimal spectrum shows a good agreement, while Kármán spectrum shows a better results at the very low frequency range, below 0.02 Hz. Since the long span bridges usually have natural frequencies larger than 0.05 Hz, it is recommended to use the Kailmal spectrum.

Acknowledgements

The authors appreciate the supports from Mr. Il-Keun Lee and Ms. Jung A Yang of the SeoHae monitoring center and Dr. Jong Chil Park and Dr. Chan-Min Park of the Korea Highway & Transportation Technology Institute. This work was supported from Samsung Engineering & Construction.

References

(1) Park, Jong-Chill, Park, Park, Chan-Min, Song, Pill-Young, 2004, Structural Behaviour Evaluation of SeoHae Cable Stayed Bridge Using Measurement Data, KSCE, 24(2A), 249-257.

(2) Simiu, Emil, and Scanlan, Robert H., 1996, "Wind Effects on Structures," John Wiley & Sons, Inc., New York.

(3) Open Meteorological Observatory of Korea, 2006, http://www.weather.go.kr/

(4) Solari, G., and Piccardo, G., 2001, Probabilistic 3-D turbulence modeling for gust buffeting of structures, Probabilistic Engineering Mechanics 16, 73-86.

(5) Davenport, A. G., 1961, Quart. J. Royal Meteorol. Soc., 87, 194.

(6) Kaimal, J. C., Wyngaard, J. C., Izumi, Y., & Cot_e, O. R, 1972, Quart. J. Royal Meteorol. Soc., 98, 563.

(7) Lumley, J.L., Panofsky, H.A., 1964, The structure of atmospheric turbulence, Jon Wiley & Sons, Inc., New York.