

## **Field Measurement of Wind Characteristics in Mountainous Valley Terrain**

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### **ABSTRACT**

When bridge spans wide valley in mountainous terrain, wind field at the bridge site exhibit remarkable non-stationary spatio-temporal characteristics. Researches about the wind field characteristic and the aerodynamic stability of bridge at such valley terrain are relatively weak. The regulations about wind resistant design of bridge at mountainous valley terrain in the codes of every countries are far to meet the requirements. With the promotion of west development in China, more and more long-span suspension bridges will be built to span the valleys in mountainous terrain. This put forward urgently requirements on the clear understand of wind field characteristics in valley terrain and its effect on the aerodynamic stability of suspension bridge. Based on the wind field measurement system of Lishui super span suspension bridge with main span of 856m, quantitative descriptions of wind field characteristics at valley site will be given by the analysis of data from field measurement, and the reasonable values for the power spectrum and spatial correlation of wind field will be studied. As results, some fundamental information are obtained which provide useful reference for the wind resistant design of bridge located in mountainous valley terrains.

### **0 Introduction**

with the deepening of West Development Strategy of Chinese National Economy, more and more of long span bridge will be constructed in the west mountainous area, especially the bridge crossing over the valley terrain are the key of the infrastructure. With the increase of the span length, significant decrease of the structural damping and natural frequencies of the bridge occur. Thus, the bridge structure becomes more flexible and more susceptible to wind induced vibrations. While a bridge is designed across deep valleys in mountainous valley terrain, the wind field at the bridge site is greatly affected by the local complex topographic condition. When the wind flows over the mountain valley terrain, wind is obstructed and deflected by the mountains and flow separation usually

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occurs downwind along the mountains. Moreover, the flow can accelerate or decelerate as it moves through valley. Therefore, wind characteristics over the mountain valley terrain are extremely complicated. So the conventional methods used to describe wind fields characteristics in a homogenous flat terrain are no longer suitable. If the conventional methods used to describe the wind field characteristics in a homogenous flat terrain were adopted for the wind design of the structure in those areas, inaccurate or even wrong results could be obtained. And normally there are no definite specifications in the Code about the design wind speed of bridge located at valley terrain.

Under such situation, it is of great importance to obtain the characteristics of the wind field in the complex mountainous valley terrain for the wind resistant design of long span bridge. Many researchers (Hyun et al., 2000; Lubitz et al., 2007; Sarah et al., 2009; Li et al. 2010; Massimiliano et al., 2013;) have investigated the wind characteristics over complex terrain and presented many important observations for wind engineering applications.

Due to the difficulty of time consuming and economy cost of field measurement, most of the above mentioned studies are carried out by model test or numerical simulation method. However, Wind field measurement has the huge advantages of instantaneous, synchronous, real, and effective. So it will be more suitable for the study of wind in bridge site of valley terrain. In this paper one field measurement system of wind characteristics of Lishui River Bridge are introduced and the wind field characteristics in mountainous valley terrain are presented which will provide effective reference for the similar situation project.

## 1 Engineering Background

Lishui Bridge which located at west mountainous area part of Hunan Province is taken as engineering background. This bridge is a one of the Single span steel truss suspension bridge with the main span of 856m, the main girder dimension is 28m wide and 6.5m high, and the height from the surface of bridge deck to the bottom of valley is nearly 400m. Due to the interference of the valley topography effects, wind field at the bridge site has the characteristics of strong gust, strong turbulence, non stationary and complicated spatial distribution. And such wind field have produced great effect on the bridge aerodynamic stability such as flutter and buffeting. In order to study the wind field characteristics in the bridge site and it effect on the normal operation of bridge, one system of a multi-point synchronous wind observation system is installed on the Lishui River bridge. The arrangement of the wind measurement system can provide better service for the Lishui River Bridge operation, and can provide the necessary reference for the design ,construction and normal operation of other bridges in mountain terrain.



Fig1 Picture of Lishui Bridge

## 2 Field measurement systems

The field measurement system of the wind characteristics in the valley at the Lishui Bridge site are composed of 3 different parts, including the station at the middle span, station at the tower and the station of reference. In order to keep the three different data acquisition station working simultaneously, the GPS time giving instrument is adopted. The sampling frequency is set at 4Hz, and all data are stored not only in the local hard disk but also transferred to the center station located in the University 350 kilometer far away by Wireless method.

### 2.1 Station at the Middle Span

Along the bridge span, 3 anemometers were installed. In order to induce the influence of the main girder on incoming wind flow, the anemometers were installed 7 meters above the surface of the bridge. At the position of 1/4 and 3/4 of the span, Young 05305L anemometers were used, and at the middle span the Young 81000 three-dimensional sonic anemometers was arranged on the top of the main cable of bridge. The real arrangement of the span station is shown in figure2. The monitor data of incoming flow in this station can provide the distribution information of wind along lateral direction of the valley which provides an important basis for the design of wind load on the longitudinal section of the main girder.



Fig2 Anemometer arranged in the middle span

### 2.2 Station at the Tower

For the station at the bridge tower, 3 anemometers were used, including two young 05305L propeller wind speed meter and one Young 81000 three-dimensional sonic anemometers. From this station the vertical wind profile at bridge site would be measured. As can be seen, in order to eliminate the disturbance of huge bridge tower on the incoming flow, limited by the site condition, two young 05305L anemometers were installed on first line of the hanger 12meters away from the bridge. One is at the height of 86m from the surface of bridge girder, and the second the at 50m position, as shown in figure 3. The three-dimensional sonic anemometer was installed on the tope a 7m high support pole. Through monitor data of this station, the mean wind profile of incoming flow can be analyzed.



Fig 3 Anemometer arranged on the cable



Fig 4 The reference station

### 2.3reference station

At the position 1 kilometer away the bridge in the southwest direction, a reference station of the wind velocity was established with an Young 05305L propeller wind speed meter 10 m above the ground in accordance with the prevailing wind direction, as shown in Fig4. from this station, the wind characteristic outside the valley can be obtained. Through the comparison of the measured wind data in and out valley, the influence of valley terrain on the wind field can be studied.

## 3 Results of field measurement

### 3.1 Data Processing Method

In accordance with the calculation method recommended by section 19.5.2 of the “ground meteorological observation code”, the average wind speed and wind direction is calculated, and the calculation method is as follows:

(1) The monthly mean wind speed: first of all, do the averages on daily wind speed data, then make the average on the daily mean values; the result is defined as the monthly mean wind speed.

(2) Monthly maximum wind speed (3S duration): in order to get the monthly maximum wind speed, the time history daily wind data of every anemometers were calculated using the sliding method of 1s step, 3S distance, taking the maximum value of all the 3s distance average as the daily maximum wind speed (3s), then taking the maximum wind speed(3s) of the month, that is the maximum wind speed (3S).

(3) Maximum wind speed (10 minutes): taking 1minute as step size and 10minutes as duration, then make the sliding average of every days measured wind data, take the maximum value as the daily maximum wind speed (10minutes), in the same way, the maximum of the monthly data is the monthly maximum wind speed of 10 minutes.

The typical time history of the real measurement data is shown in figure. And the typical daily maximum wind speed in the middle span in August of 2014 is shown in figure 6.

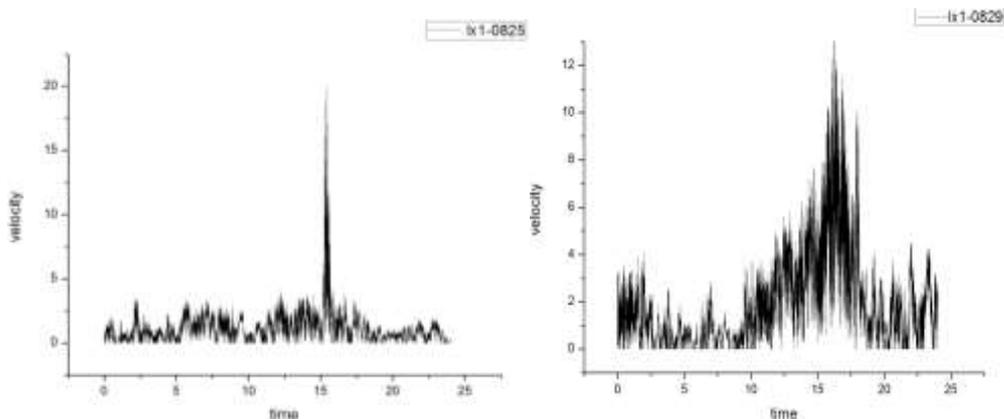


Fig5 The time history curves of measured wind speed

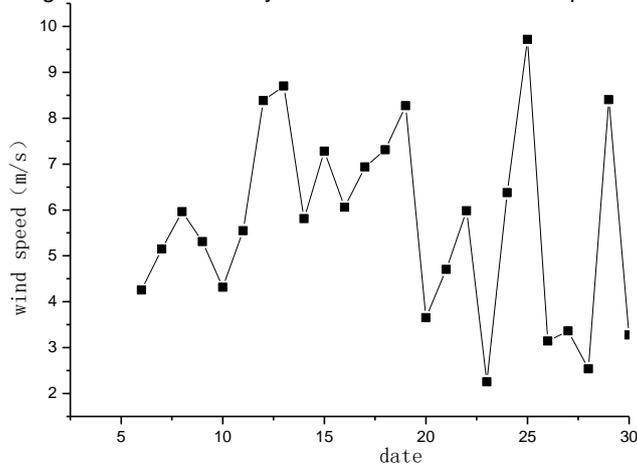


Fig 6 The typical maximum daily wind speed of middle span

### 3.2 Wind Profiles

Figure 7 shows the vertical mean wind profile measured by the tower station. As can be seen from the figure, with the increase of height, the wind speed increases linearly. In the measured height of the anemometers, the power law is not suitable for the description of wind profile. If taking the wind speed of the second anemometer (50m high from bridge girder surface) as reference, the wind profile coefficient  $\alpha$  of power law distribution can be obtained by least square method. The distribution of the fitted results is shown in figure 8, the fluctuation of the fitted power law index of wind profile is located in 0.1515~0.4109, and the average is 0.261, but probability of the value of 0.308 is largest. Taking the Code for wind resistant design of Highway Bridges of China as reference, the mean profile of wind in valley can be treated as D class.

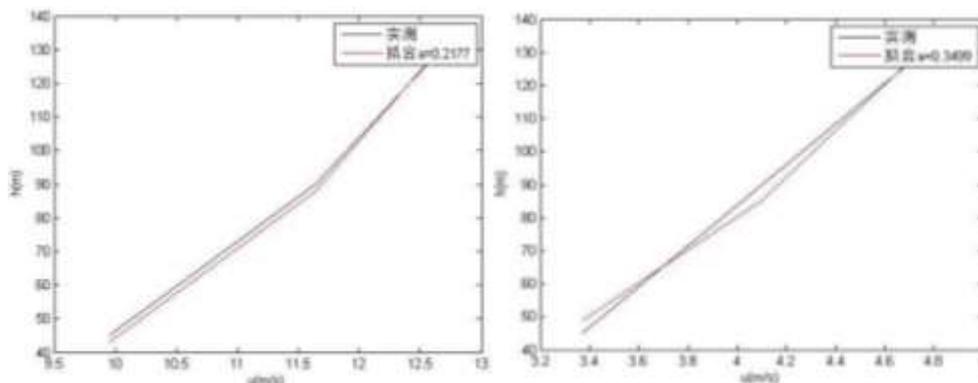


Fig 7 the typical mean wind profile measured by tower station

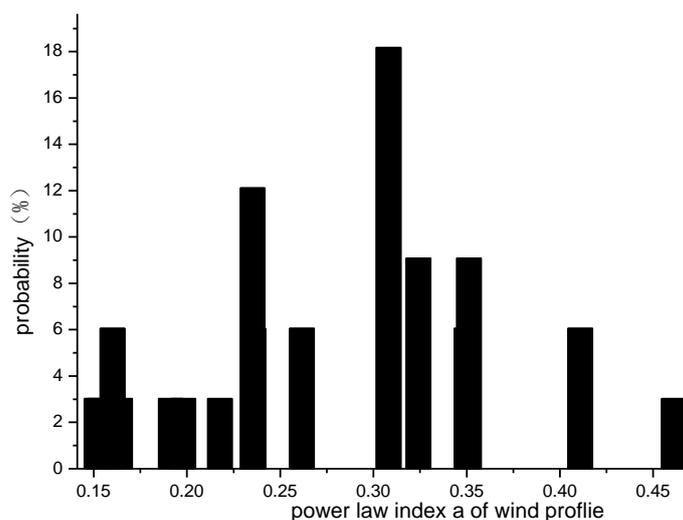


Fig 8 the probability distribution of the fitted power law index of wind profile

### 3.3 Attack Angles

The attack angle of incoming flow is analyzed through the measured data obtained from the three-dimensional sonic anemometer installed in the middle span. 100 wind samples were selected from the measured wind speed with 10minutes mean speed larger than 5m/s. Statistical analysis of wind attack angle data of the wind samples was carried out and the results is shown in figure9. For the wind attack angle, the main value fluctuation is located in the section of  $-9^{\circ}\sim 8^{\circ}$ , which is significantly larger than the specified value  $-3^{\circ}\sim 3^{\circ}$  in the code for the homogenous terrain. Since wind attack angle is a very important parameter of the bridge wind-induced vibration response, the attack angle of incoming flow in mountainous valley should be paid more attention to. According to the measured attack angle value, the Normal distribution formulation can be fitted as following:

$$f(n) = 0.2 + 4.04e^{-\frac{(n+2.2)^2}{114.0}}$$

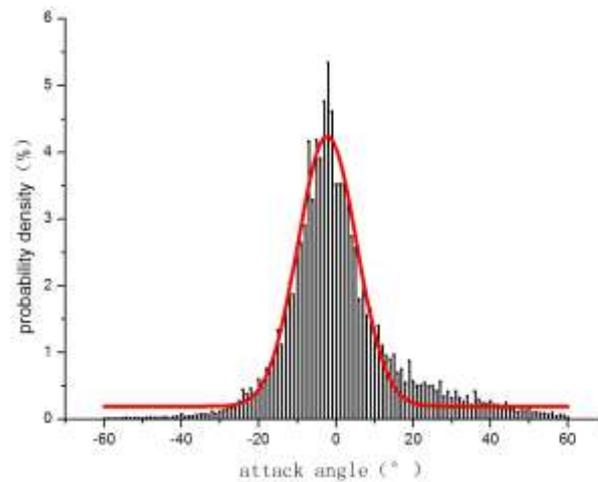


Fig 9 the probability density of attack angle of incoming flow

### 3.5 Turbulence Intensity

100 wind samples were selected from the measured wind speed with 10minutes mean speed larger than 5m/s., then the turbulence intensity of the fluctuating wind were calculated, the results is shown in fig10. As can be seen, the value of the vertical turbulence intensity are located in the section of 7.37%-24.49%, and the average is 14.56%, while for the horizontal direction, the turbulence intensity is located in the section of 14.73%-48.97% with average value of 29.12%, which is nearly two times of the vertical wind value. Figure 11 shows the distribution of  $I_u$  along with the wind speed and  $I_v$  in the vertical direction, it can be seen that the turbulence intensity  $I_u$  decrease dramatically with the increase of wind speed when the wind speed is lower than 6m/s, after that , then turbulence horizontal along wind intensity nearly keep the constant value of 25%, the  $I_v$  value have the similar distribution trend which indicated the Violent fluctuation of wind in mountainous valley.

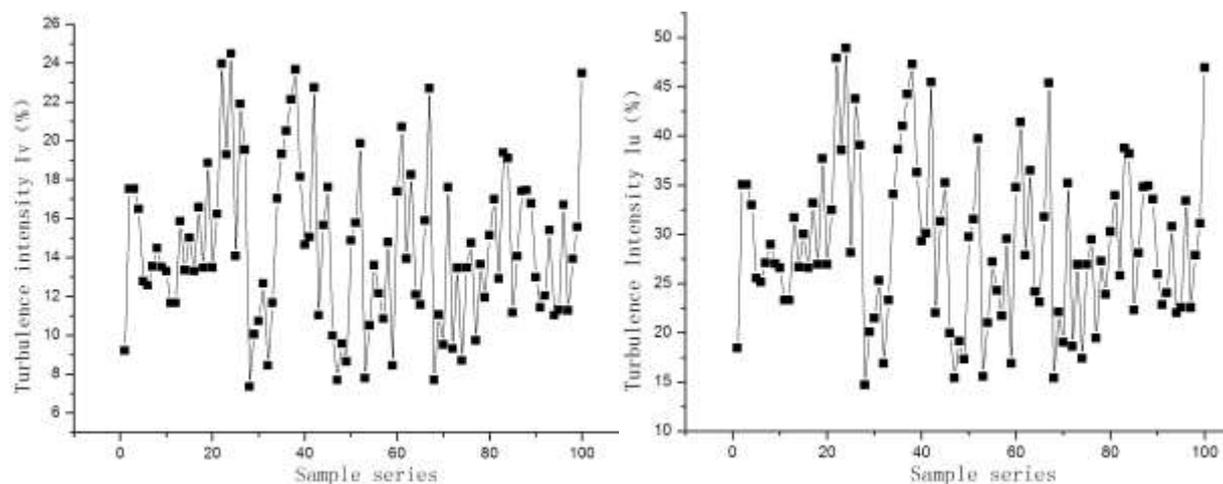


Fig 10 the turbulence intensity in vertical and horizontal wind direction

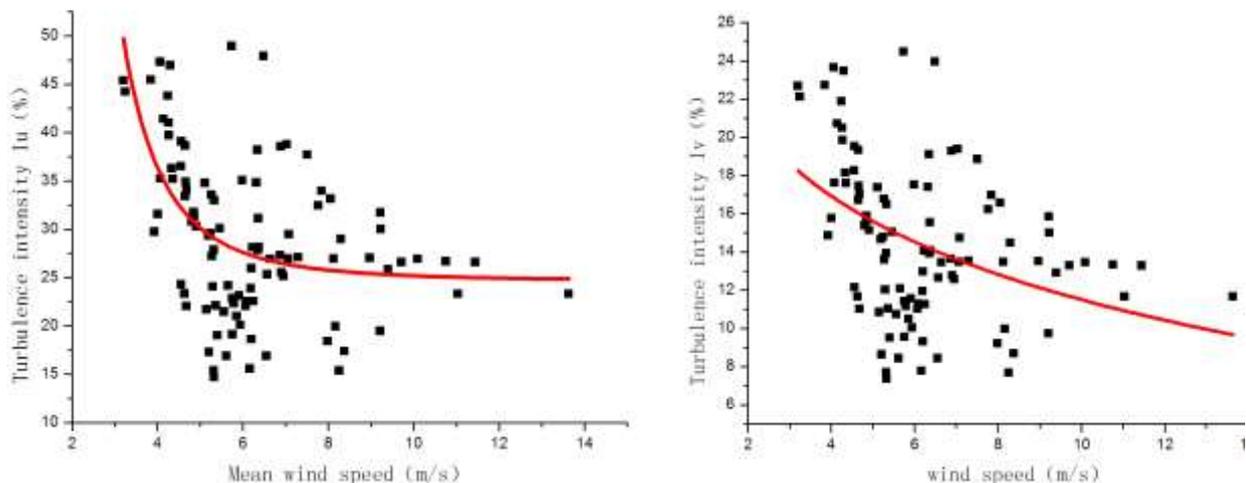


Fig 11 the distribution turbulence intensity of Iu and Iv

### 3.6 gust wind factor

The definition of turbulence and wind gust factor is both determined by the fluctuating wind speed and average wind speed. Therefore, there should have some relation between the turbulence and the gust factor. The analysis results is shown in Figure 13, the fitting result indicated that there is a liner relation between the gust factor and the turbulence intensity.

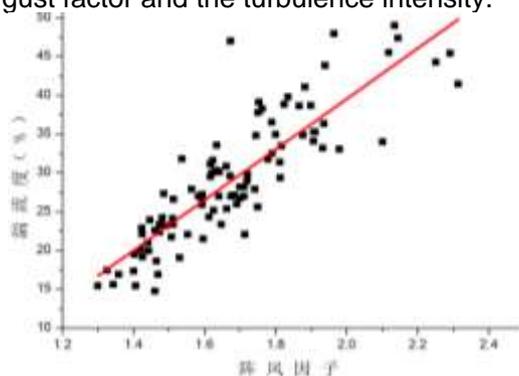


Fig 11 the relation between gust factor and turbulence intensity

## 4 Conclusion

The wind field measurement system of Lishui bridge is introduced, through the analysis of the measured wind flow data, characteristic of wind speed of bridge, wind direction, wind attack angle and wind fluctuating properties are studied, preliminary results of wind field in mountainous valley and relevant conclusions are obtained:

- (1) The complexity of the terrain condition at the bridge site determines the complexity of the wind field. the wind profile in the valley of Lishui River Bridge site is more complex, single power law index of wind profile can not represent the distribution of the valley terrain wind speed with height variation.
- (2) The fluctuation of the attack angle of incoming flow in the valley terrain is significantly larger than the value  $\pm 3^\circ$  specified by code for the homogenous terrain, this should been pay more attention during the design of bridge in valley.

(3) Measured turbulence intensity value decrease with the increase of height, and the gust factor increase linearly with the increase of turbulence intensity. The average value is not quite different from that of the Class D specified in code, and the average value of the statistics is stable.

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